Lighting and Robotic Integration

NASA In Space Inspection Workshop (ISIW)

July 15, 2014

Michael Wright

Software, Robotics, and Simulation Division

Engineering Directorate

NASA/JSC

281-483-4798, michael.d.wright@nasa.gov

Introduction

While imaging is the most prominent aspect of inspection, lighting also plans plays an important role. Without the proper lighting, an imager's performance is not optimized and important details can be lost. These lost details can mean the difference between clearing a vehicle and declaring it unsafe for entry. In this presentation, the impacts of lighting on imaging will be discussed. In addition, information will be provided on integrating with the ISS robotic systems.

Agenda

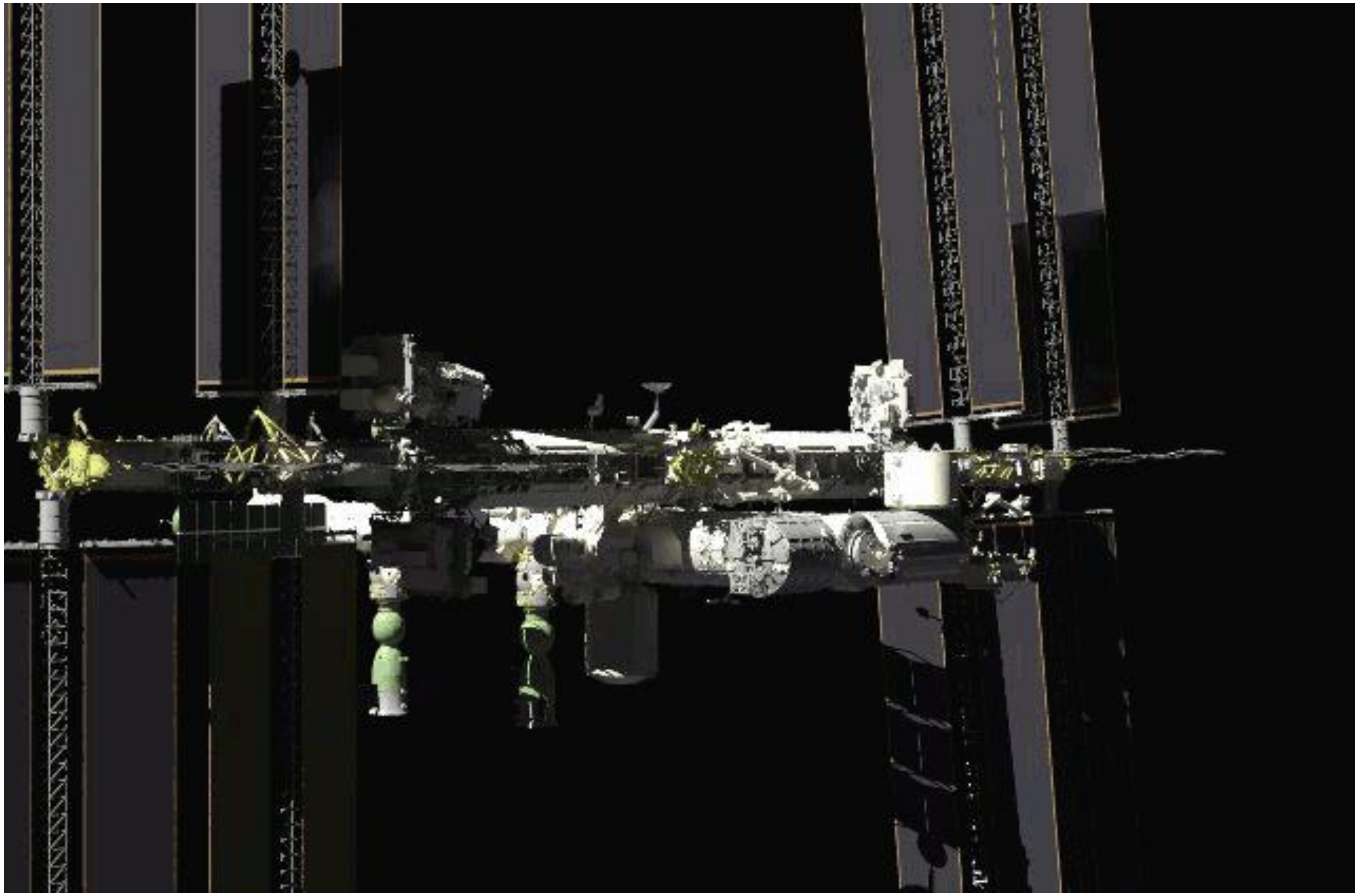
- Lighting
  - On-orbit Lighting Conditions
  - Benefits of Artificial Lighting
- Integration with ISS Robotic Systems

Contributors

- Michael Rollins – Image Analyst, background in on-orbit spacecraft external (imagery-based) inspection
- Jim Maida – Lighting Ops Subsystem Manager

On-orbit Lighting Conditions

- Natural on-orbit lighting (Sun, Earth albedo) is very dynamic
  - Sun angle relative to ISS is continuously changing through the day-pass of an orbit
  - Sunlight has a harsh shadowing effect
  - Earth albedo is better in most respects when compared to sunlight, but it is only available on certain faces of the ISS and only during the day-pass
- The following video illustrates some of the effects of natural on-orbit lighting

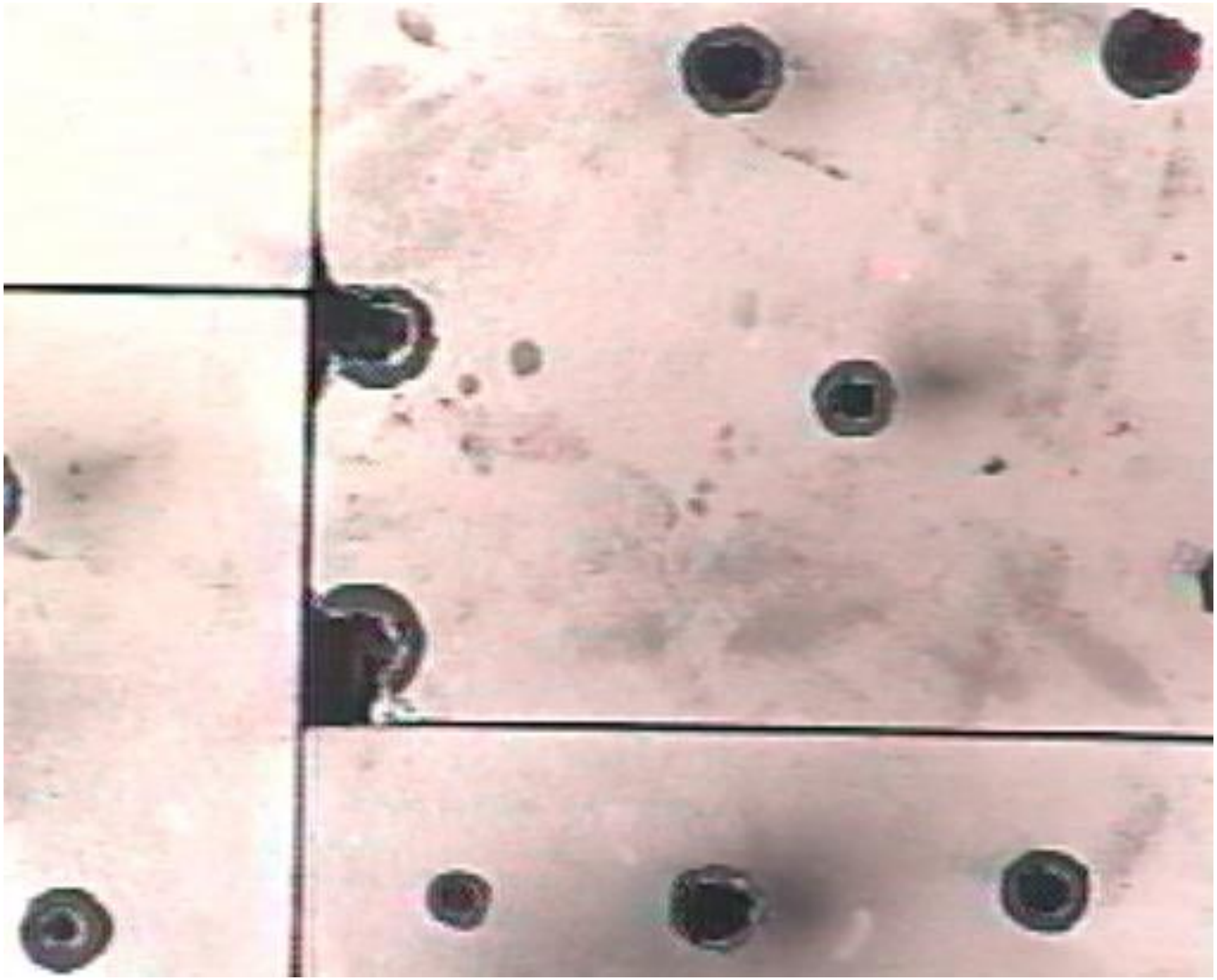


Benefits of Artificial Lighting

- In order to overcome the effects of natural on-orbiting lighting, as well as be able to collect images anytime during an orbit, it is beneficial to provide artificial illumination in conjunction with an imager
  - The specific type of illuminator will depend on a number of factors: imager capabilities, material(s) to be surveyed, range, angles of incidence, just to name a few
  - Other things to consider
    - Existing ISS artificial illumination is limited
    - Illuminator should be strong compared to the sun for daylight operation at least for the nominal range of operation to the target surface
    - Illuminator should provide for strong signal-to-noise ratio for night time operation
    - For robotic imaging surveys at night, illumination should be strong enough for effective inspection at 10' – at least 200 lux at 10' for MSS-type imaging
- The following slides illustrate some of the benefits of artificial illumination with respect detecting damage

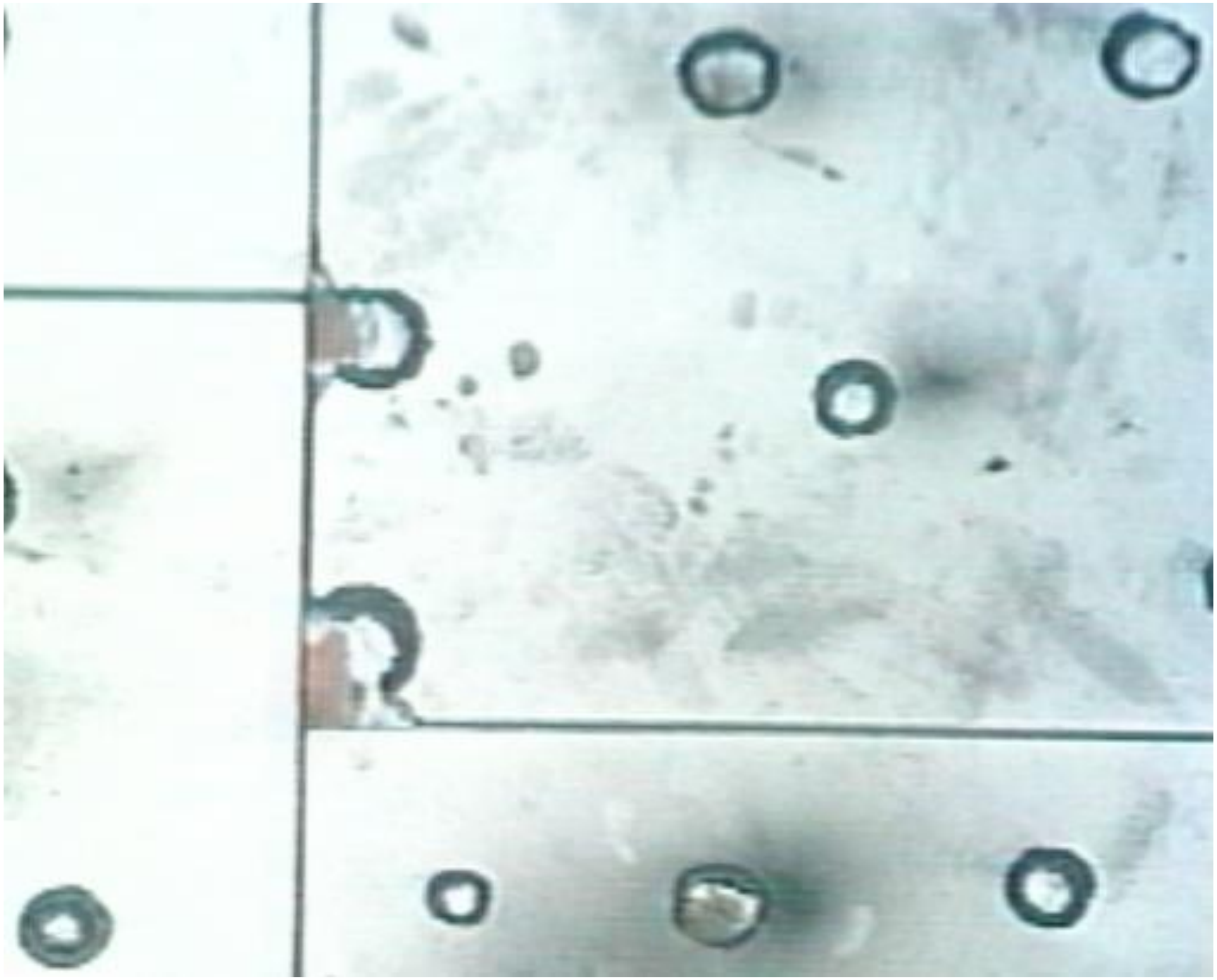
The following two slides illustrate the benefit of line-of-sight illumination in detecting Micro-meteriod and Orbital Debris (MMOD) penetration into TPS tile

Tile Damage Under Sun(like)Light



Single Frame

Tile Damage Under MSS(Like)Light

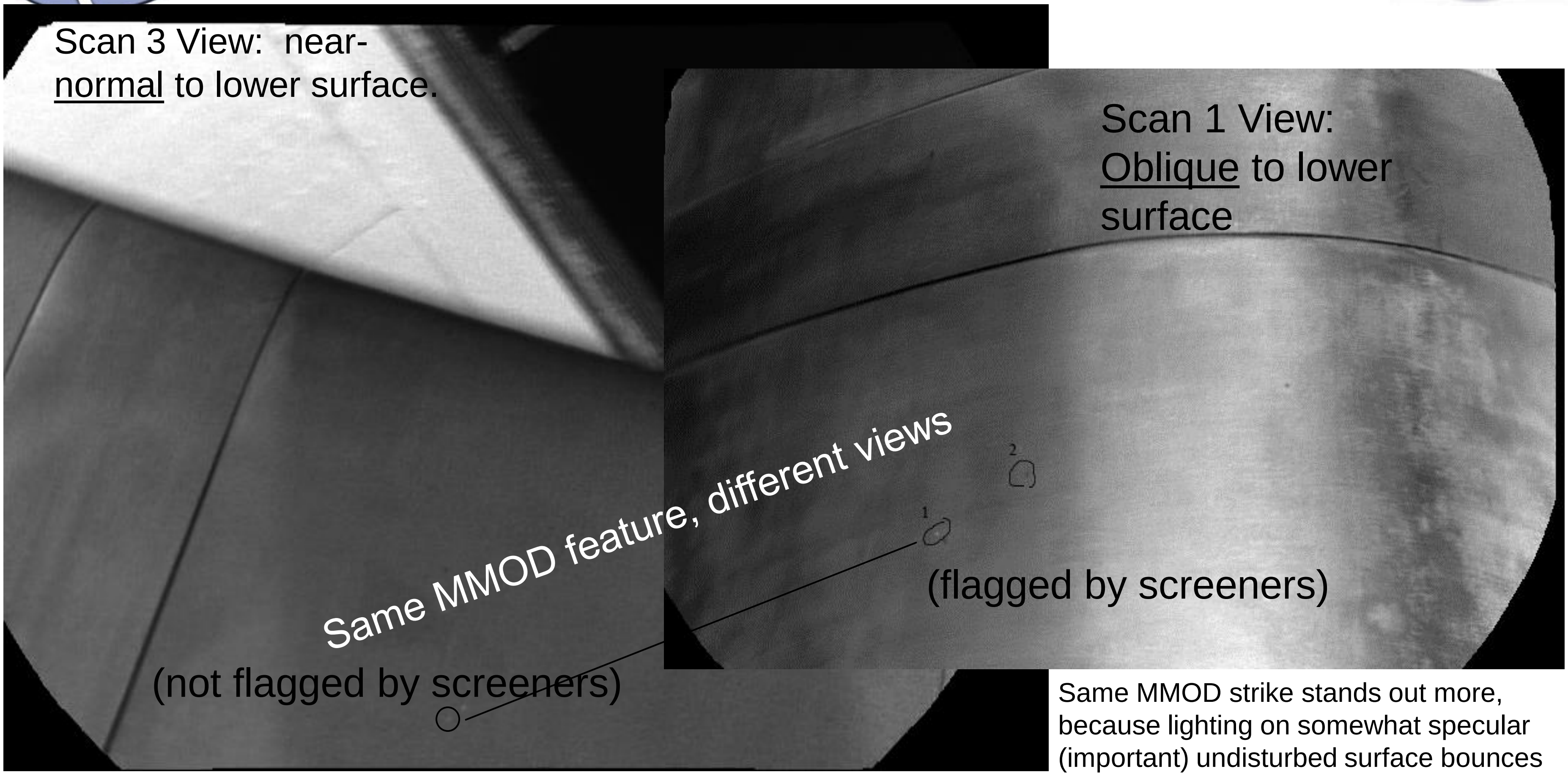


Multiple-frame average (to beat down noise)

The following slide illustrates the benefit of using a line-of-sight imager for MMOD damage detection on RCC, in which careful control of illumination and viewing incidence angle results in enhanced damage contrast

Strategic Use of Line of Sight Illumination

Example STS-120 **Panel 8L** MMOD Strike



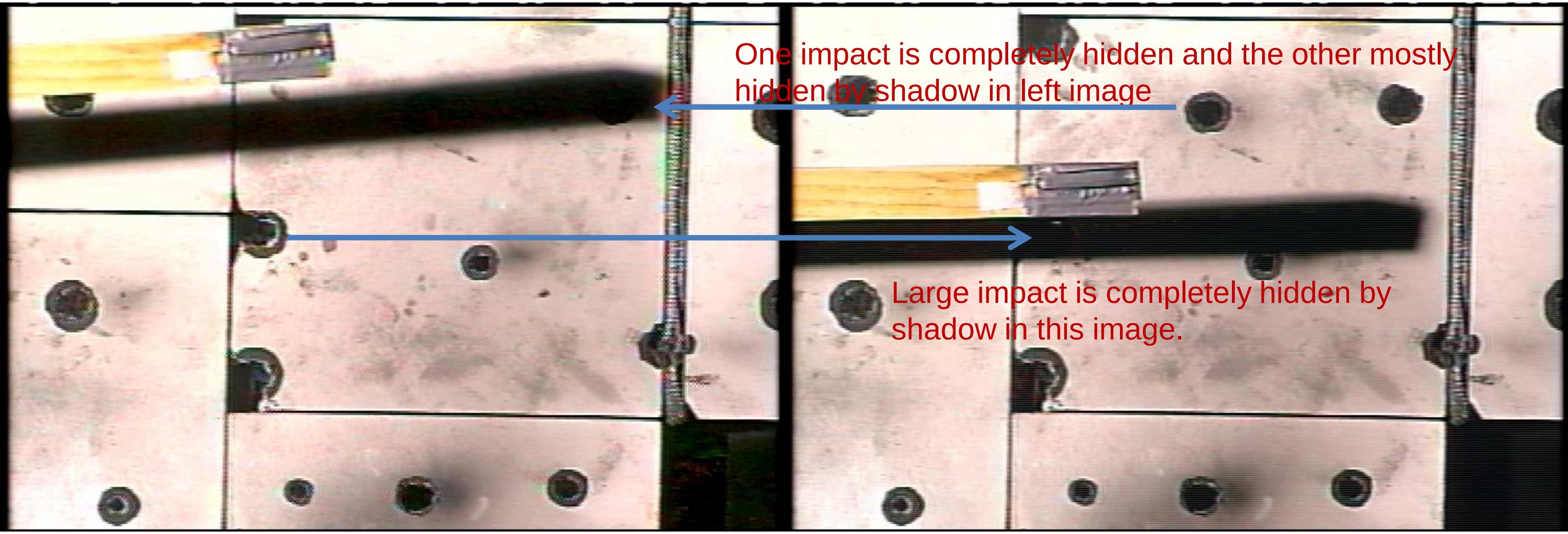
MMOD strike doesn’t stand out, because the strike and the surrounding surface both reflect light back to the camera.

Same MMOD strike stands out more, because lighting on somewhat specular (important) undisturbed surface bounces away into space, but proportionally more of the light bouncing off of the strike returns to the camera. Thus, a favorable illumination and viewing angle existed.

The strong LDRI illuminator itself provided necessary *dominant* lighting. The *location* of the illuminator (near the camera), and the partially *specular/glossy* nature of the surface ensured that a preferential viewing and illumination angle for better contrast was possible and controllable.

The following two slides illustrate how an illuminator stronger than sunlight can mitigate sun-related shadows, for inspection robust to ambient lighting conditions

Problem: For MSS-type imagers, operating in daylight, passing shadows can completely obscure damage

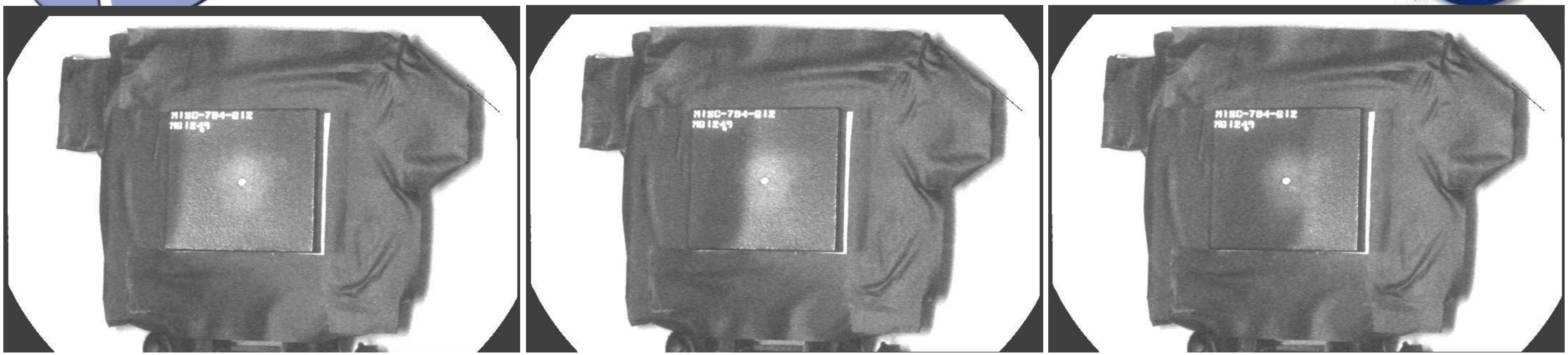


Shadow obscures all of one impact crater and most of another (see right image for reference).

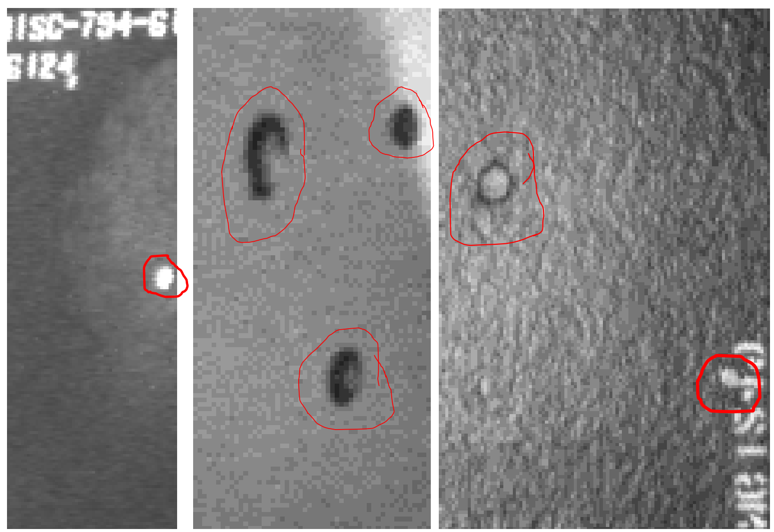
Shadow obscures a large impact crater.

Unlike for the LDRI, MSS-based inspection in daylight may involve shadowing that completely obscures surfaces. Note, however, that Earthshine, if present, can partially illuminate a shadow.

Sample LDRI Imagery



Sequences of "Level-1" LDRI Images for which a simulation of hardware shadowing the "sun" is demonstrated. Note that both tile impact features (the impact in the center and the impact adjacent to the serial numbers) remain clearly visible and detectable regardless of the progress of the shadow, because of the intensity of the LDRI illuminator.



Example Hypervelocity-impact Entry Holes and Annotations by Screeners in Blind/Subjective Detection Testing. Note a small entry hole (diameter 0.19") in the upper-left by the serial numbers that was not circled. The larger entry hole in that image (the one that was circled) has a diameter of 0.27". The left and right images are of black tile cases and the center image shows a white tile. All three images have an impact with a diameter on the order of 0.25".

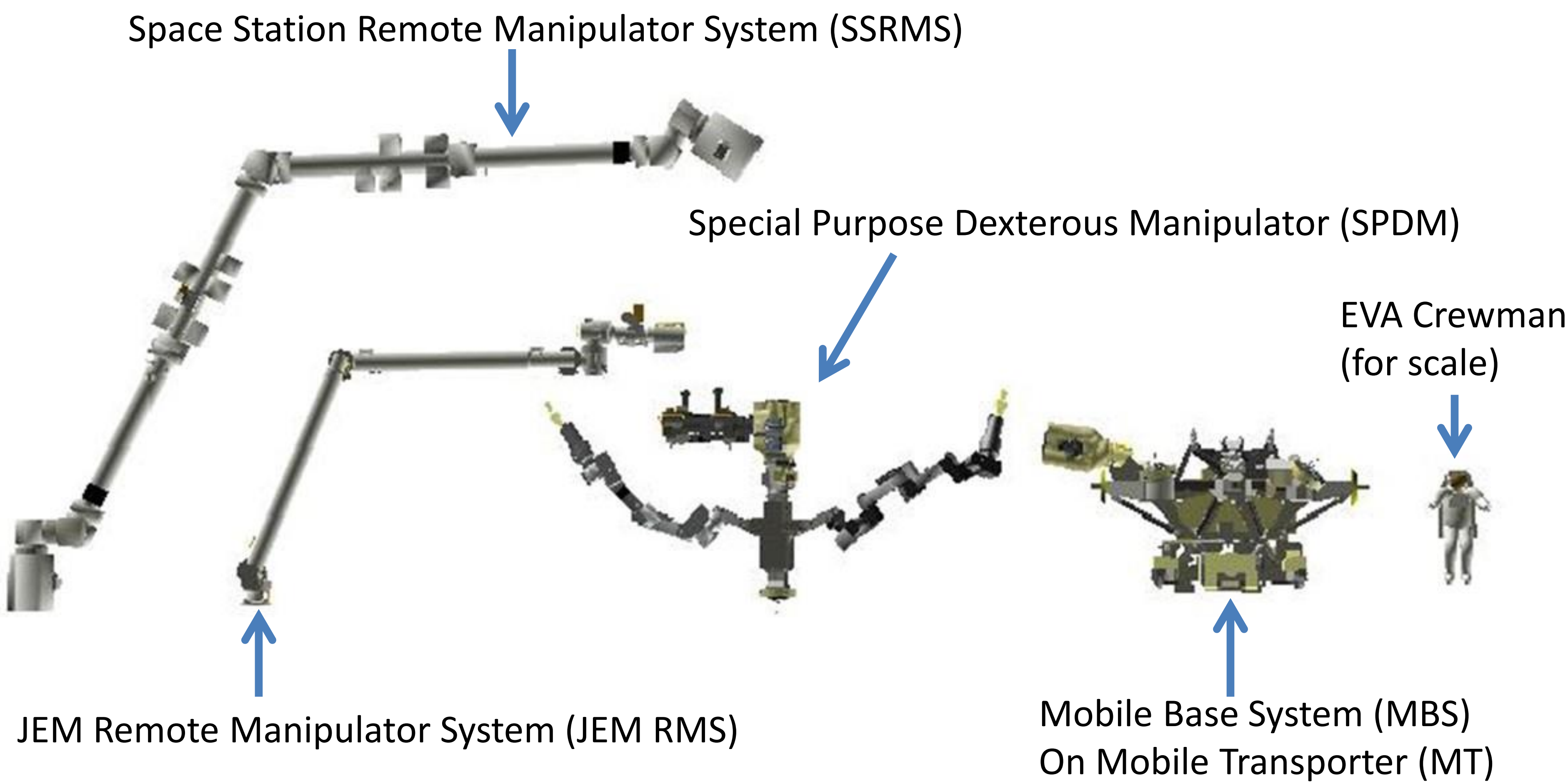
Integration with ISS Robotic Systems

External payloads interact with ISS robotic systems in one way or another.

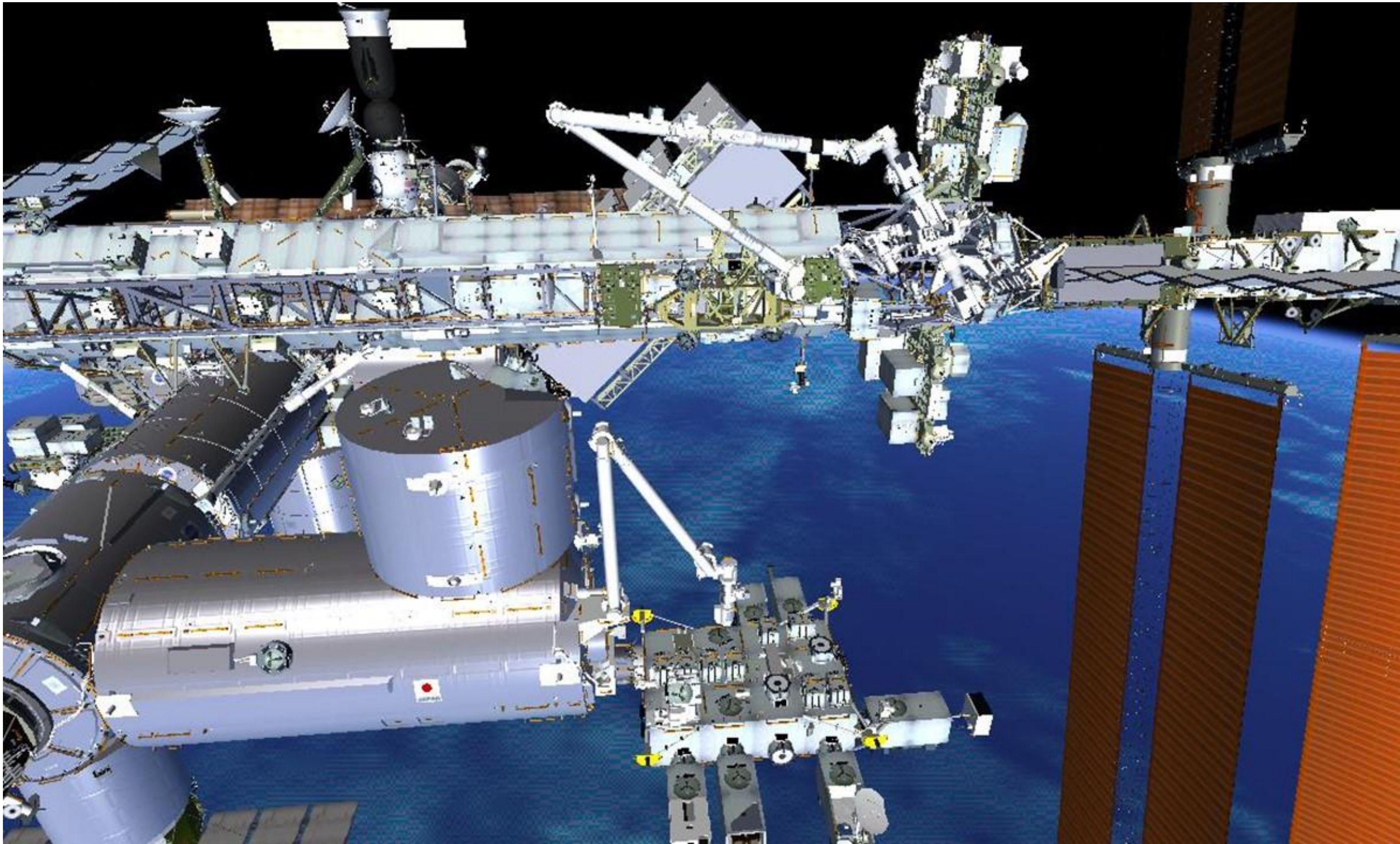
Robots on ISS provide a lot of flexibility, but that also brings increased options and complexity that must be taken into account.

The purpose of this presentation is to provide an overview of the robotic systems and the options available.

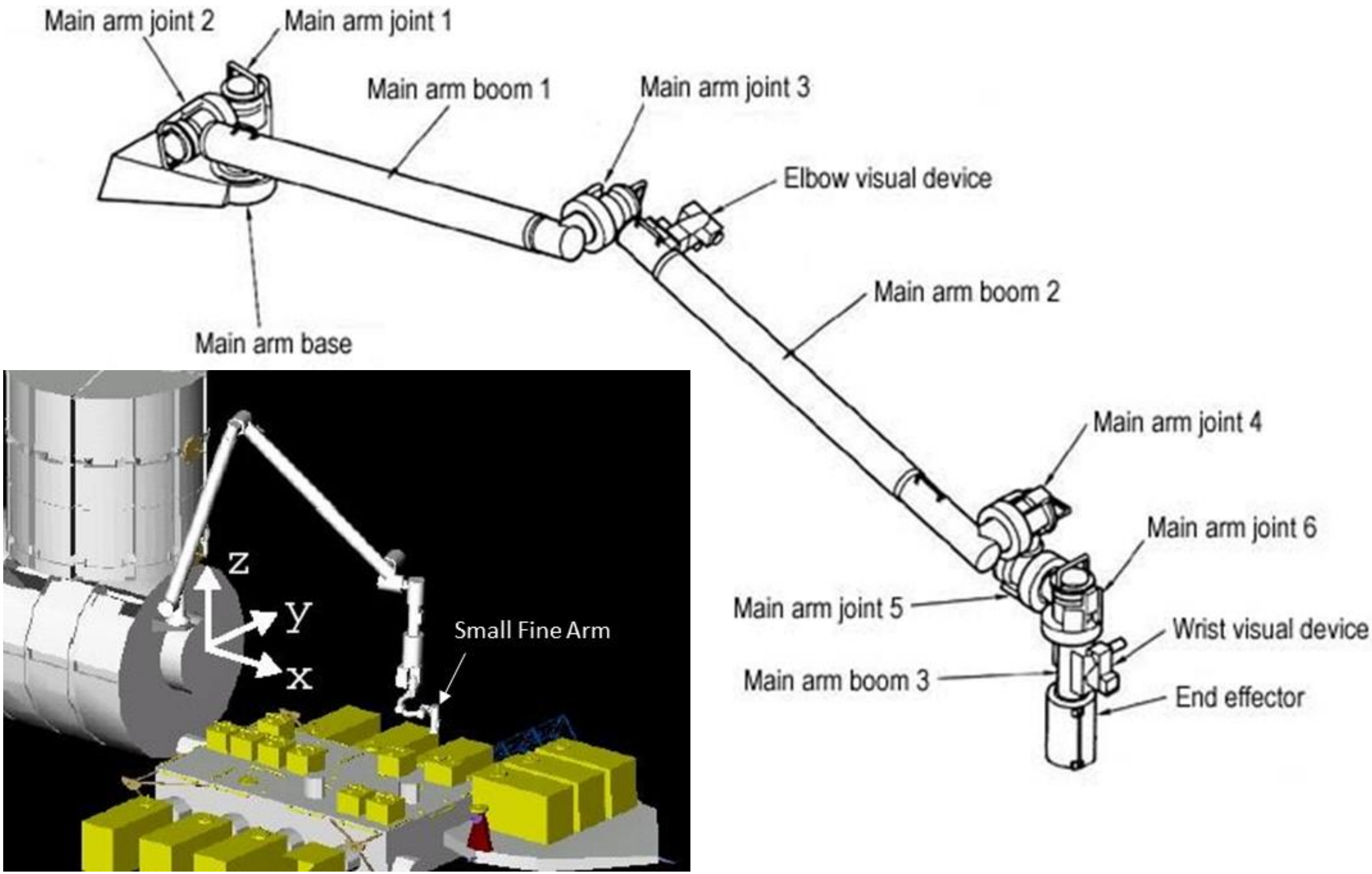
ISS Robotic Systems



ISS Robots

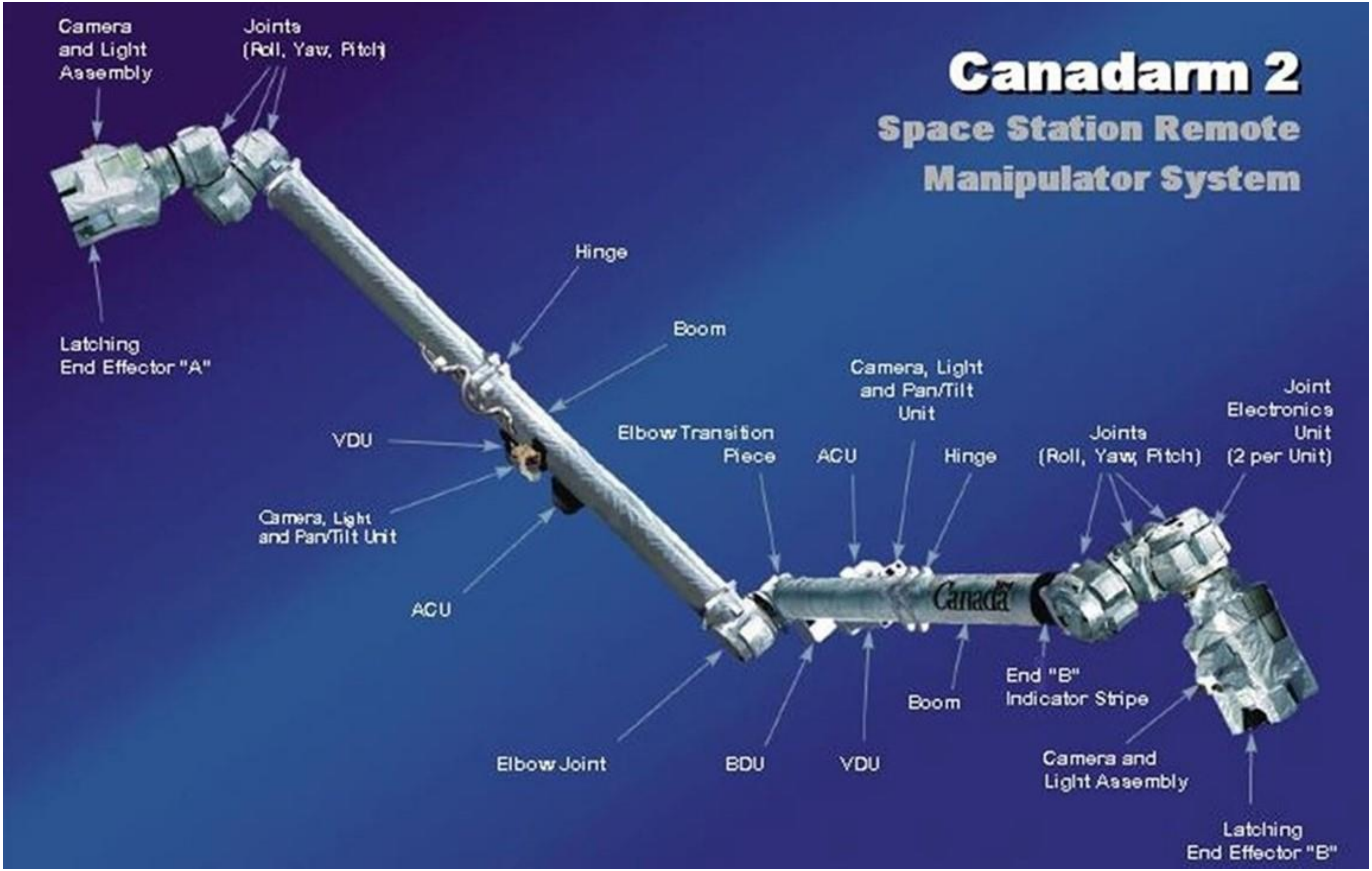


JEM RMS

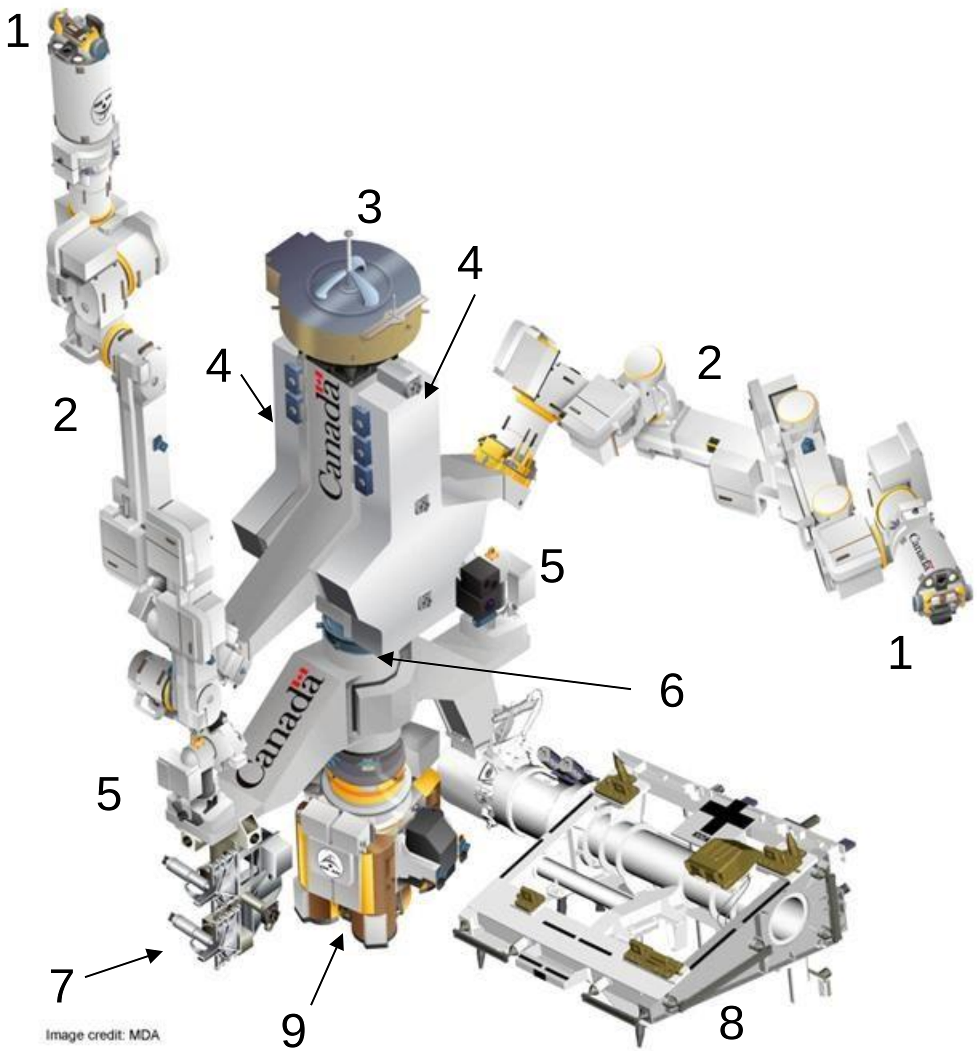


Main arm joint 2
Main arm joint 1
Main arm boom 1
Main arm joint 3
Elbow visual device
Main arm boom 2
Main arm base
Main arm joint 4
Main arm joint 6
Main arm joint 5
Wrist visual device
Main arm boom 3
End effector
z
y
x
Small Fine Arm

SSRMS

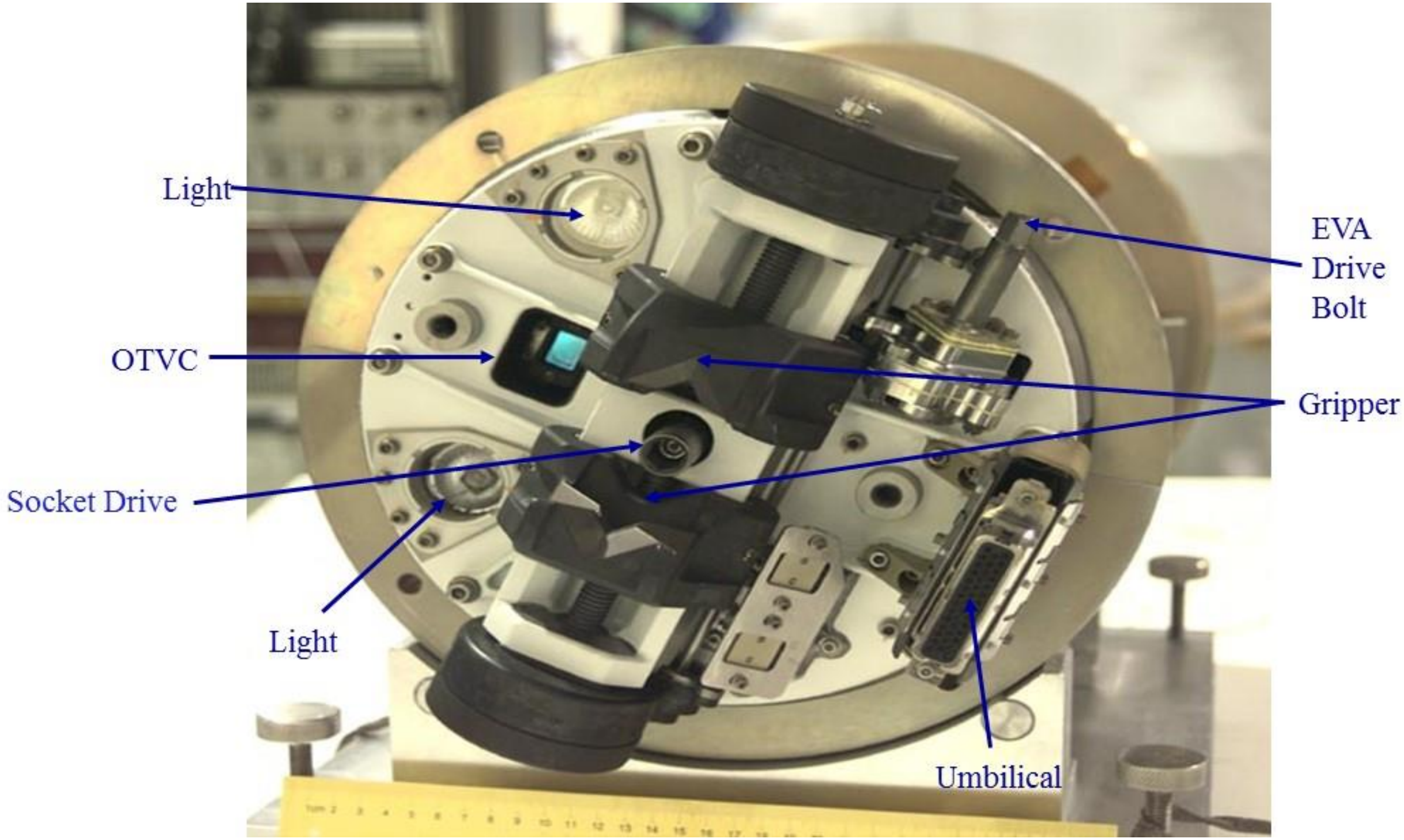

Canadarm 2
Space Station Remote Manipulator System
Camera and Light Assembly
Joints (Roll, Yaw, Pitch)
Latching End Effector "A"
Hinge
Boom
VDU
Camera, Light and Pan/Tilt Unit
ACU
Elbow Transition Piece
ACU
Camera, Light and Pan/Tilt Unit
Hinge
Joints (Roll, Yaw, Pitch)
Joint Electronics Unit (2 per Unit)
Canada
Elbow Joint
BDU
VDU
Boom
End "B" Indicator Stripe
Camera and Light Assembly
Latching End Effector "B"

SPDM Component Overview

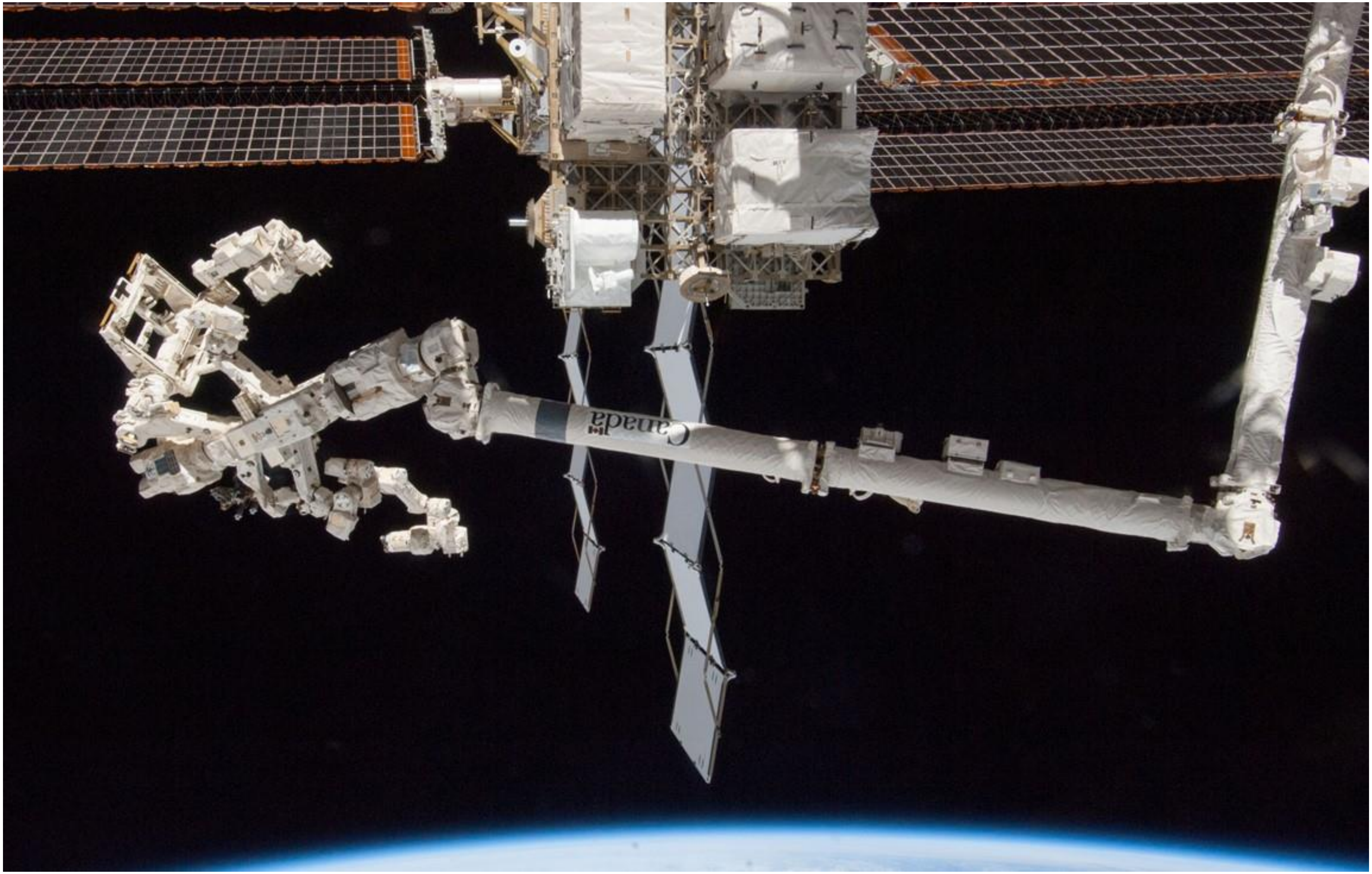


1. Two ORU/Tool Changeout Mechanisms (OTCMs)
2. Two arms
3. Power & Data Grapple Fixture (PDGF)
4. Two Electronics Platforms
5. Two Camera/Light/Pan-Tilt Assemblies (CLPAs);
6. Body Roll Joint
7. Tool Holder Assembly (THA)
   a) 2 Robot Micro Conical Tools (RMCTs)
   b) Socket Extension Tool (SET)
   c) Robotic Offset Tool (ROST)
8. Enhanced ORU Temporary Platform (EOTP) with 2 PFRAMs and 3 Stanchion sets
9. SPDM Latching End Effector (LEE) with Camera/Light Assembly (CLA)

ORU Tool Change-out Mechanism (OTCM)



SSRMS with SPDM



Transportation – How To Get To ISS And Why It Matters

Internally and Externally Launched Payload Capable

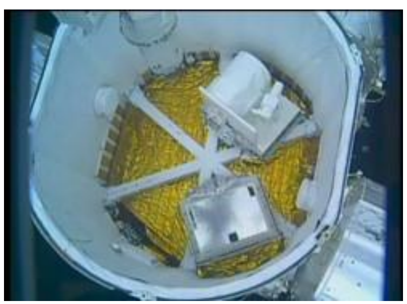
Internally Launched Payload Capability Only

SpaceX Dragon

JAXA HTV

Orbital Cygnus

ESA ATV



Dragon "Trunk"

Exposed Pallet (EP)

Direct installation to ISS location via robotics

Internal Payloads use JEM Airlock to get external and then installed/utilized via robotics

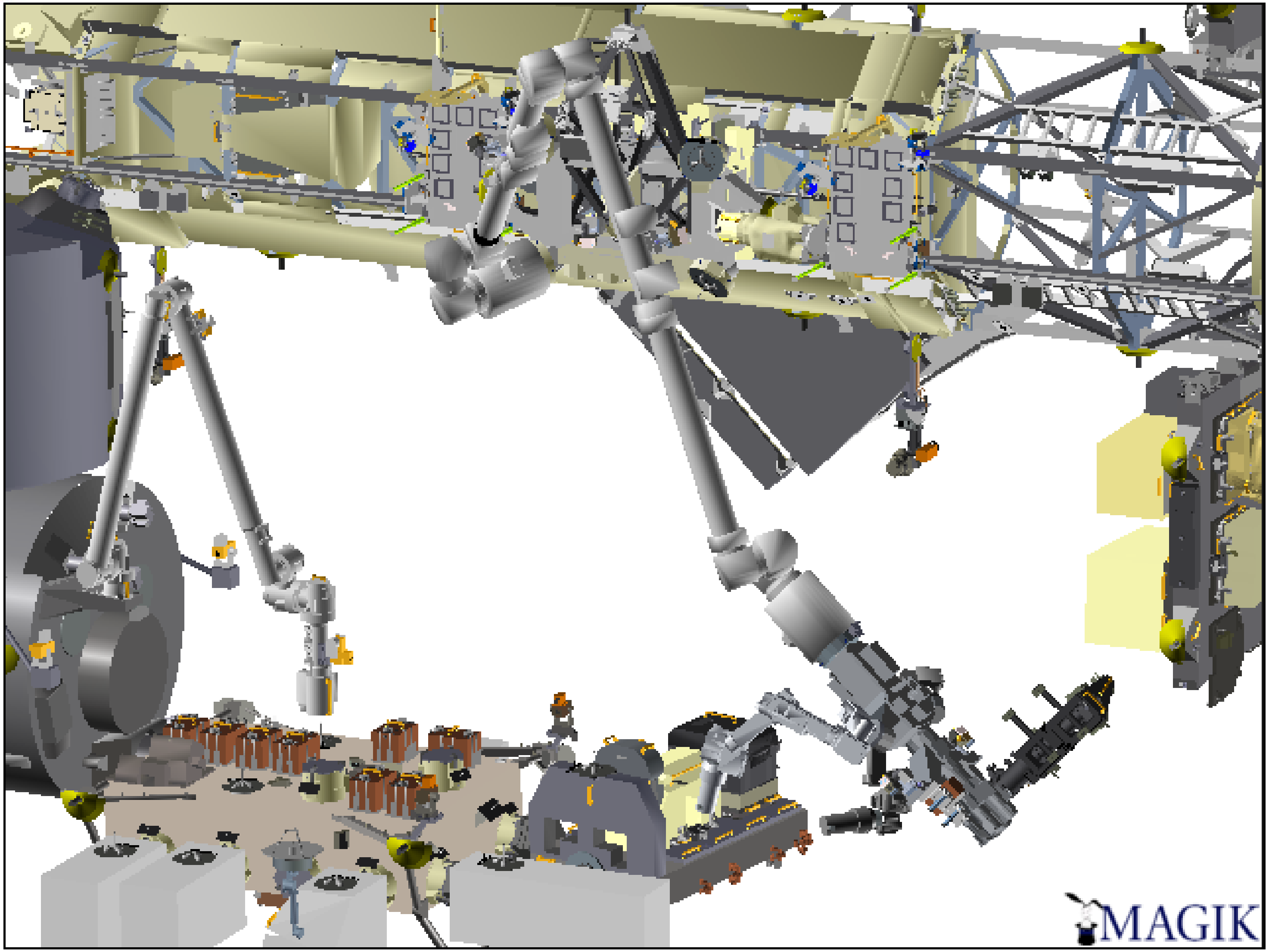
Externally Launched Payloads Removal From Launch Vehicle

SSRMS/SPDM Preparing To Enter Dragon Trunk For Payload Extraction

ISS026E024079

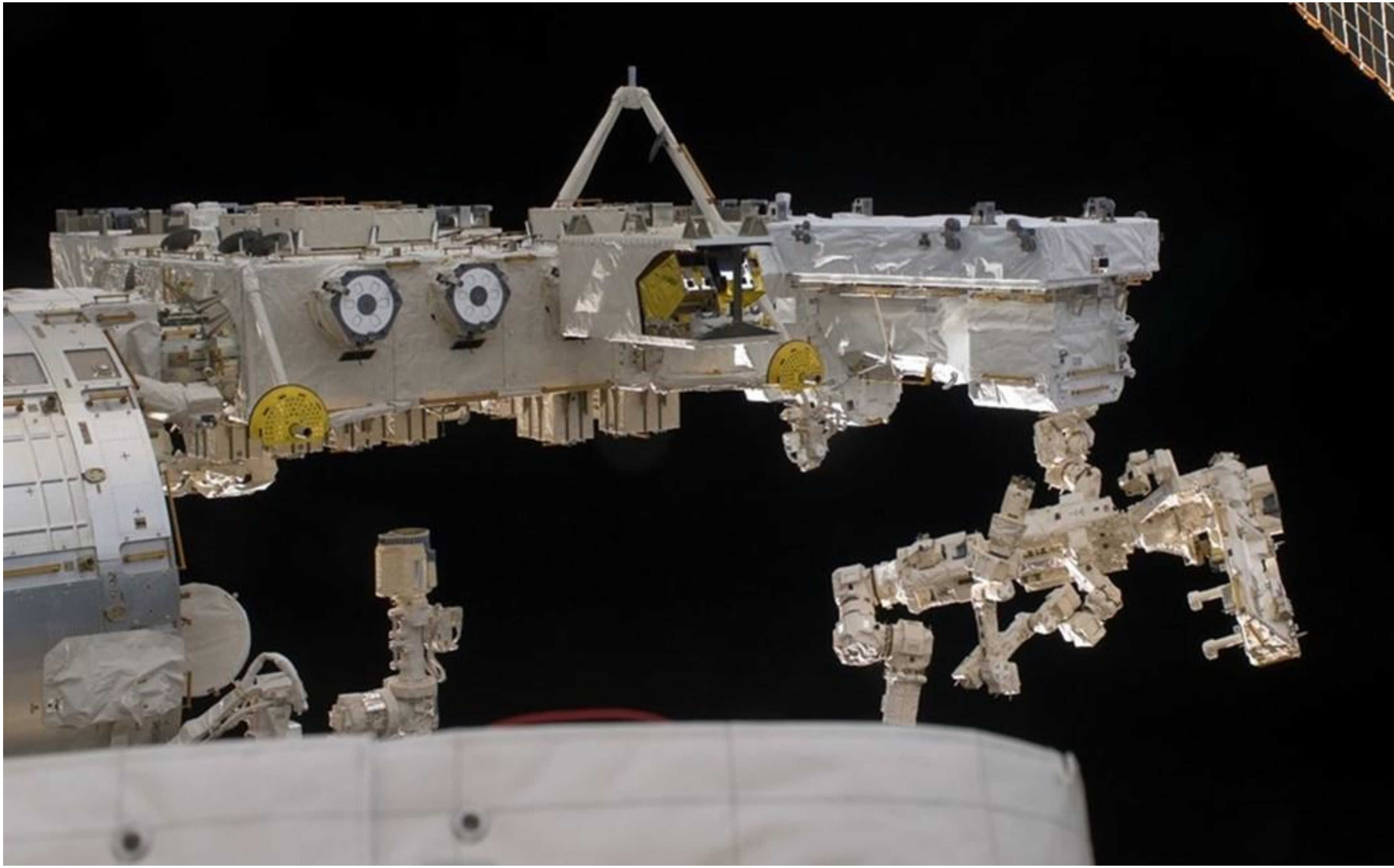
SSRMS Extracting HTV Exposed Pallet (EP)

EP Installed on JEM EF



Payloads will be removed from EP and installed on ISS (either JEM EF or ELCs)

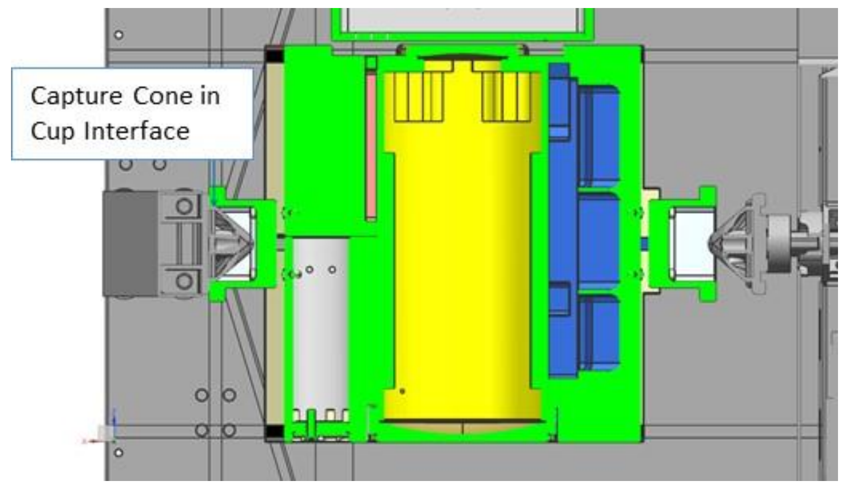
SPDM accessing ORU from EP Installed on JEM EF



JEM Airlock Usage

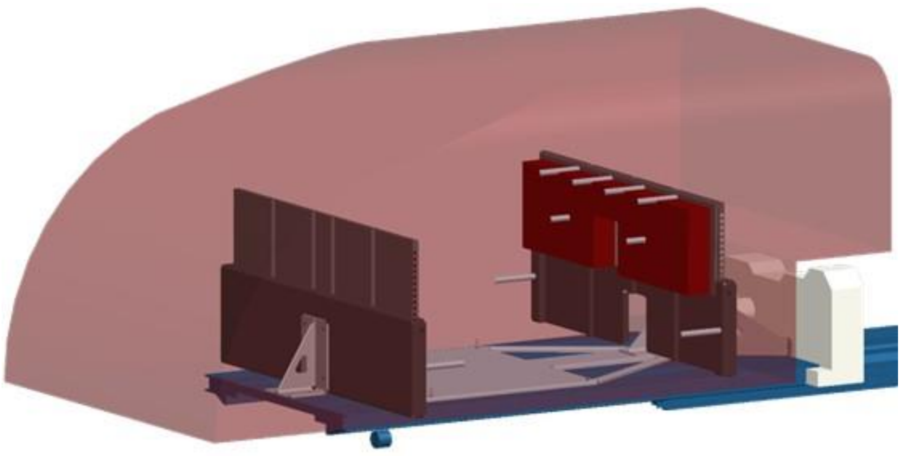
- For payloads that plan to launch internally, but then go external, the only robotic option is to go through the JEM Airlock
- There are three primary JEM Airlock interfaces for SPDM ops
  - Capture type – requires a specific slide table interface on the payload
  - Bolt-fixed type (Direct Mount) – payload carrier bolts directly to the slide table which would necessitate a robotically-actuated payload release interface between the payload and the carrier
  - JEM ORU Transfer Interface (JOTI) – does not require any specific payload interfaces which allows it to accommodate hardware not specifically designed to utilize the native JEM Airlock interfaces

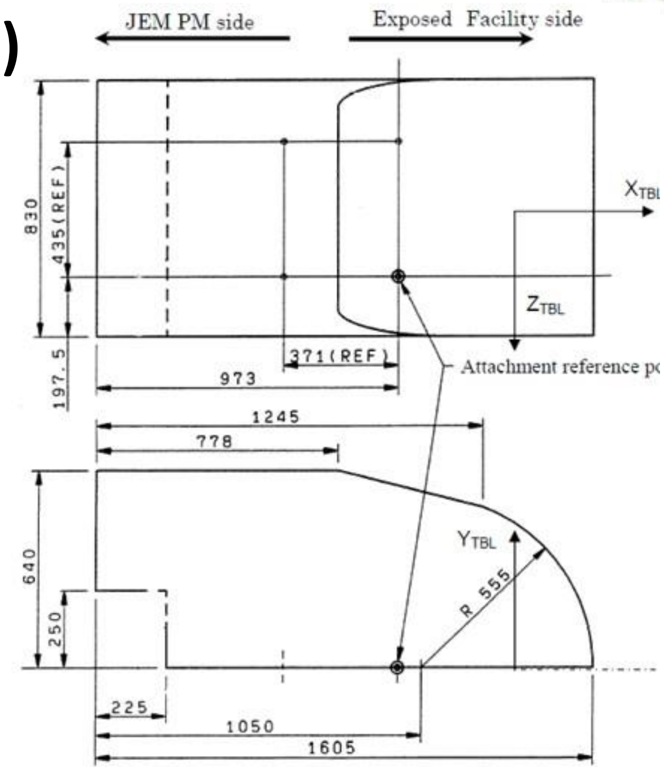
JEM Airlock and Slide Table

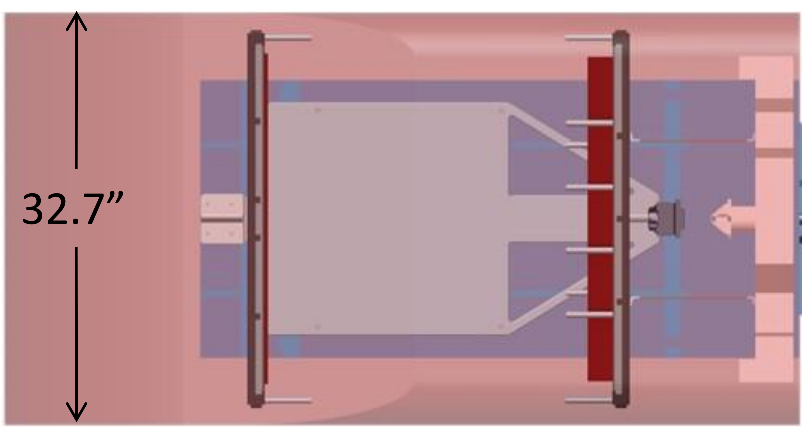


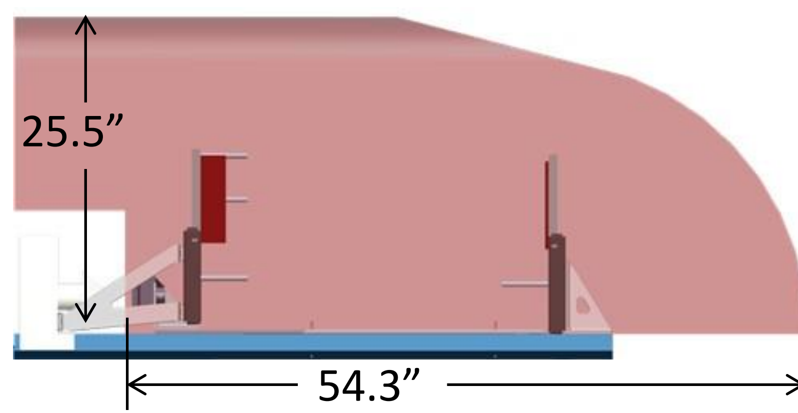
JEM Airlock Table Capture Type ORU (cross section on interfaces)

JEM Airlock Envelope
(with JOTI installed for reference)

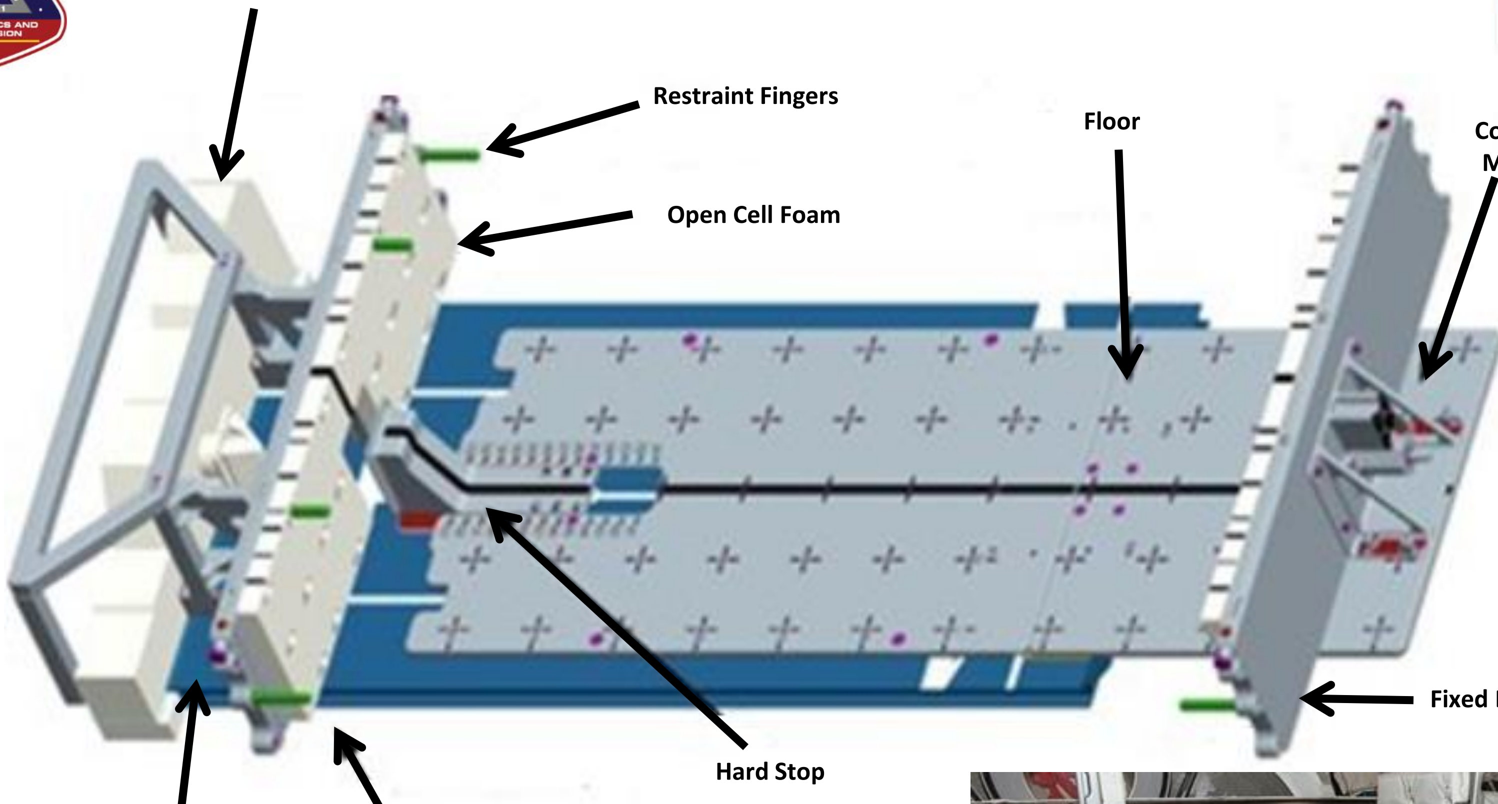




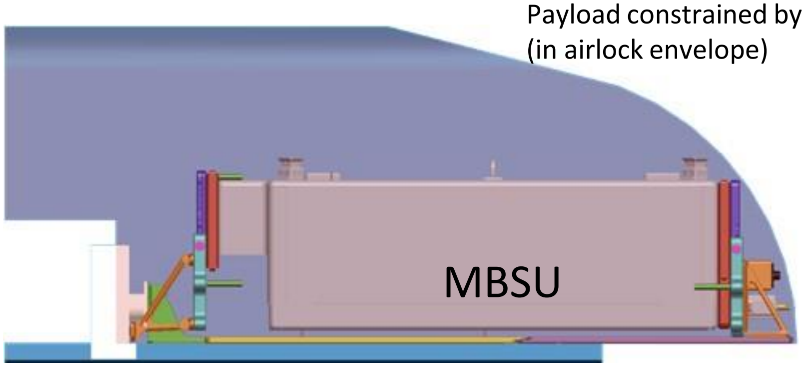




JEM ORU Transfer Interface (JOTI)

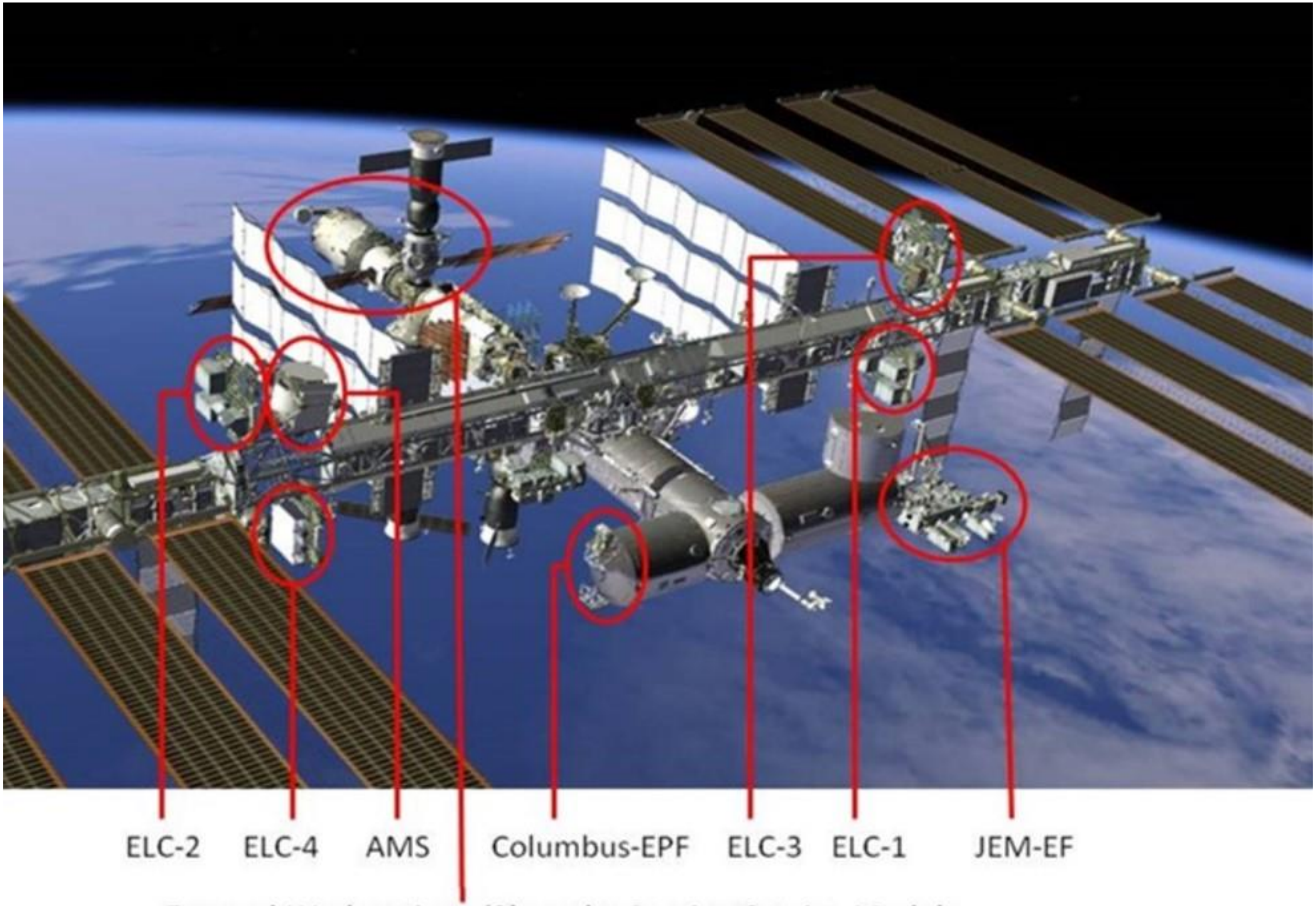


Payload constrained by JOTI walls
(in airlock envelope)

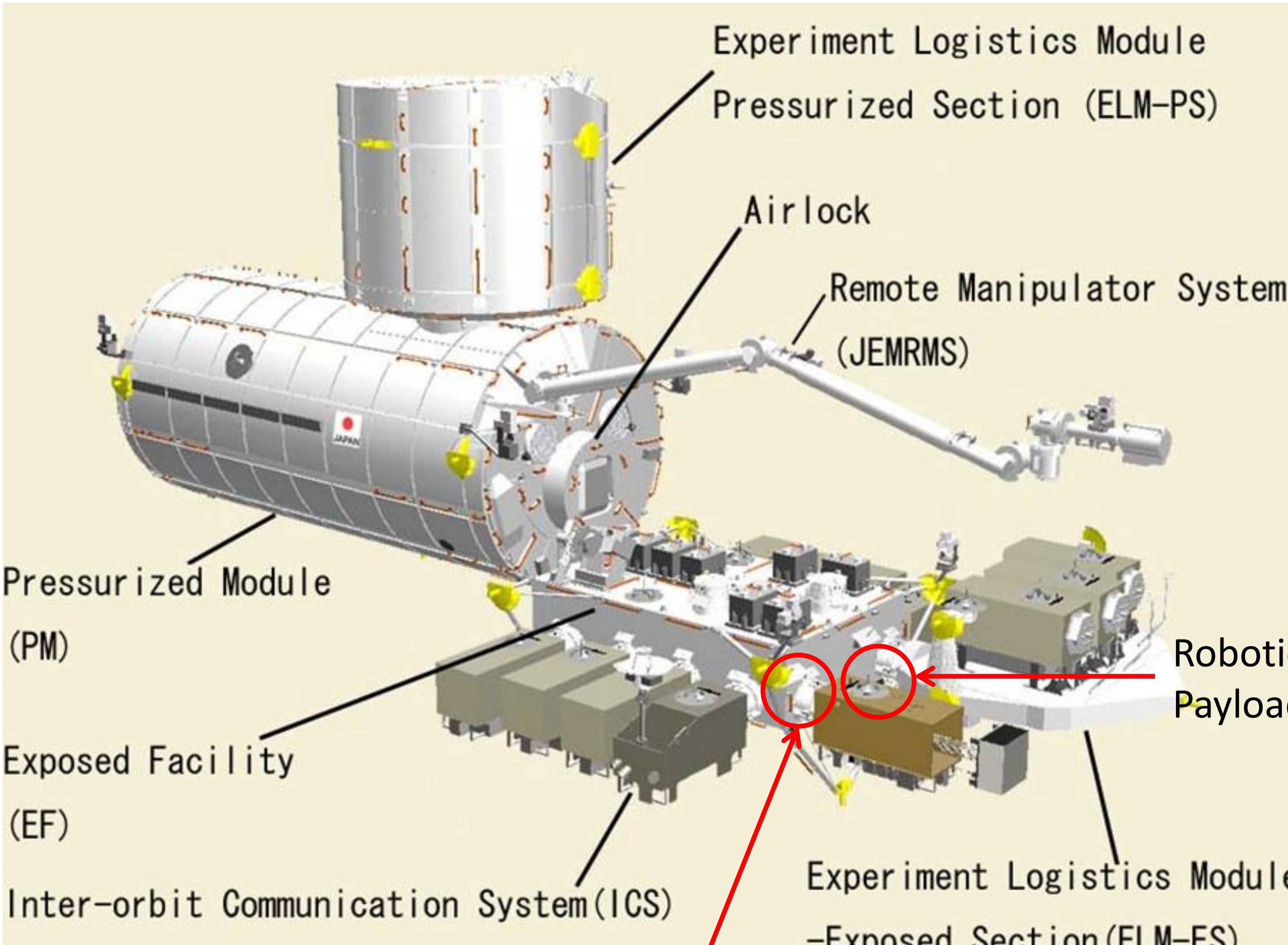


CLPA in JOTI

External Payload Locations
Where You Go Determines Type Of ISS Interface



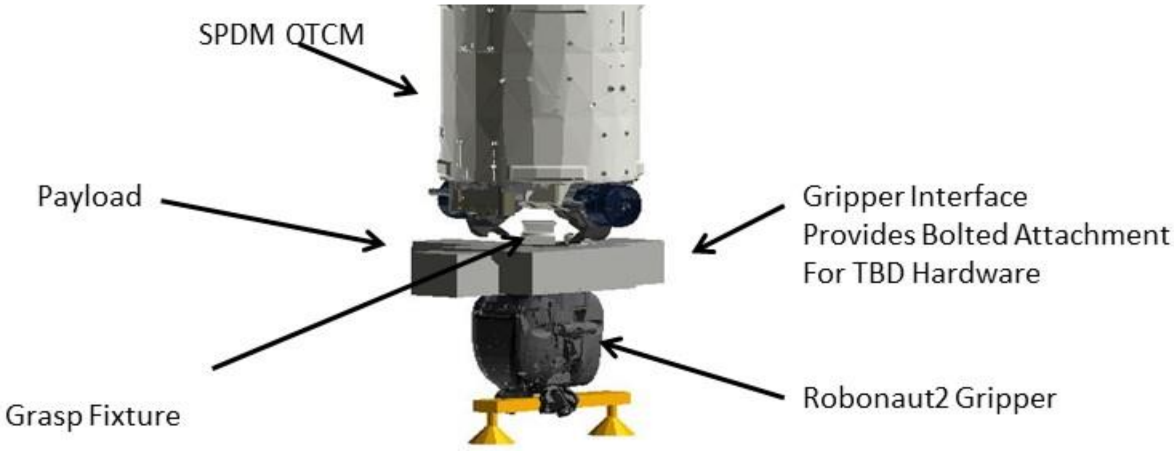
JEM Payload Sites

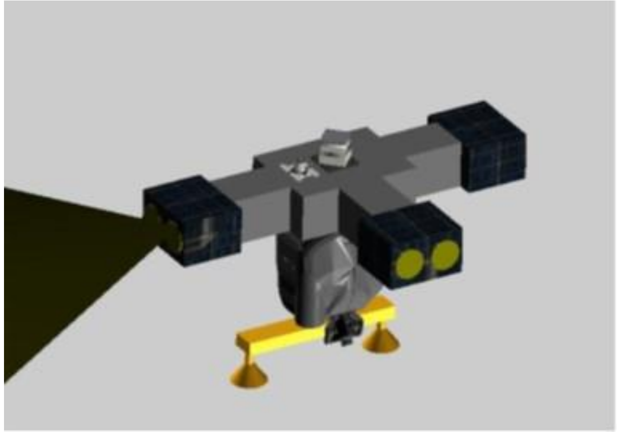


Robotic interface to Payload is FRGF

Payload interface to JEM EF is the EFU

Gripper Interface Concept (not existing capability)



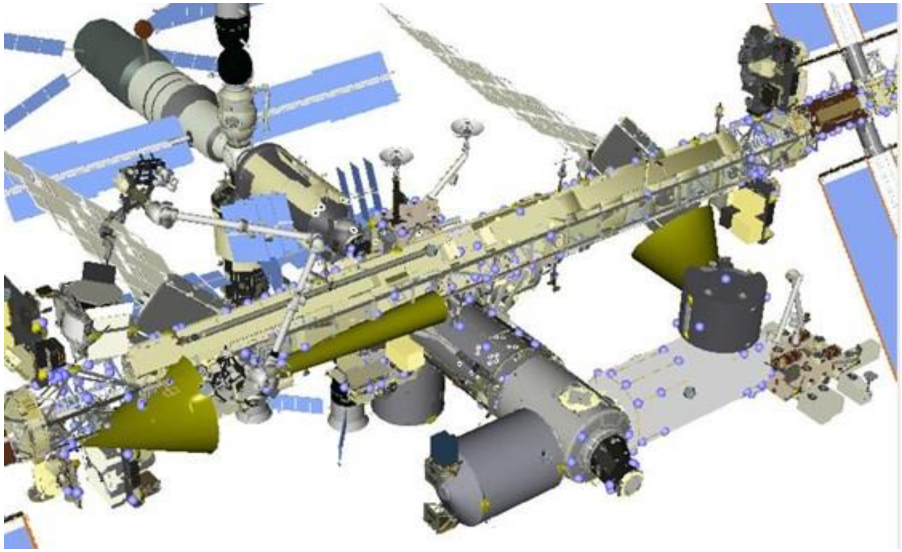


Payload Attached To Handrail

Gripper Attach Options Provides Extensive Location Options

- Handrails
- Micro Fixtures
- WIF Sockets

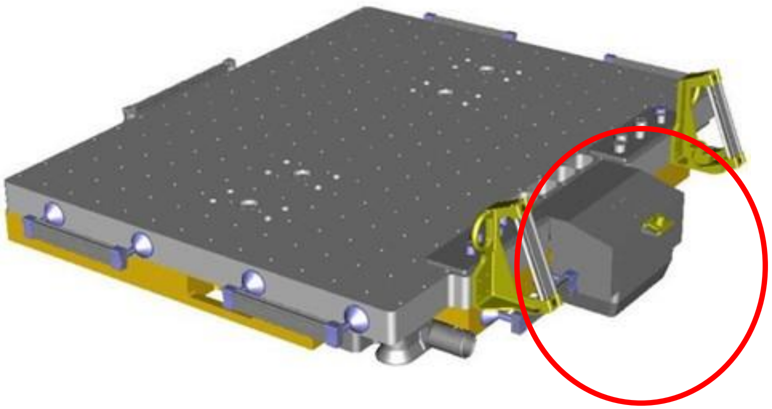
Payload would need to provide power and data (via wi-fi)

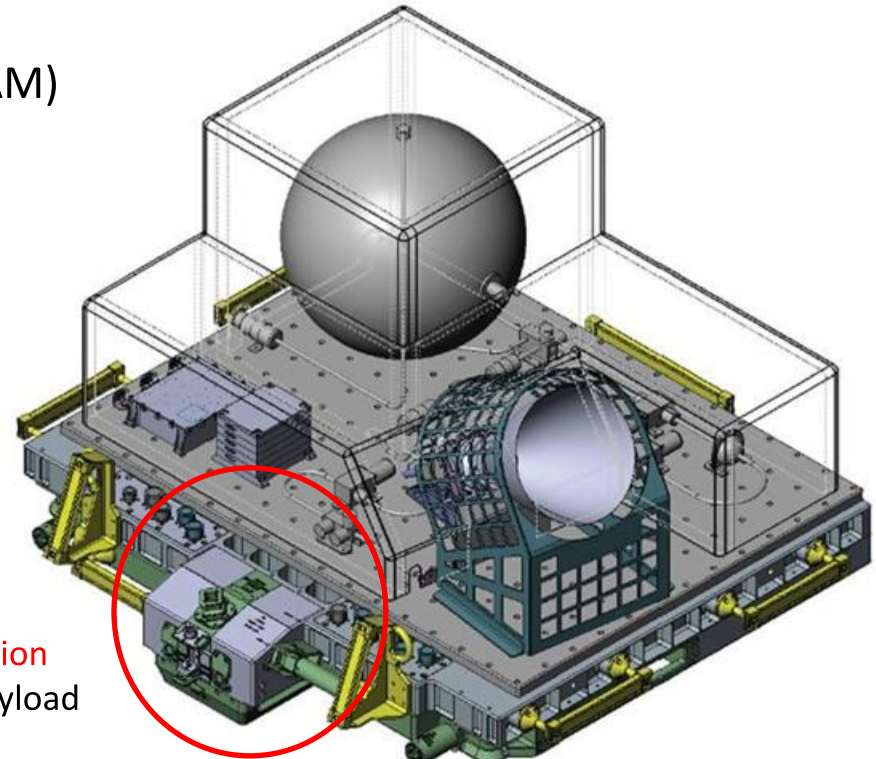


WIF Socket Locations

Interfaces for Launch or ISS Location

Flight Releasable Attachment Mechanism (FRAM)





Robotic Interface for transportation is with the FRAM and not the payload

The payload and the Active FRAM interface are both attached to and separated by an adapter plate. There are different sizes of adapter plates that can be used:

- Large Adapter Plate Assembly (LAPA)
- Medium Adapter Plate Assembly (MAPA)
- Small Adapter Plate Assembly (SAPA)
    - EXPRESS Pallet Adapter (ExPA) for ELCs
    - Columbus External Payload Adapter (CEPA) for Columbus EPF
- Light-Weight Adapter Plate Assembly (LWAPA)

Compatible with Dragon Trunk, HTV EP and ELCs

Payload Interfaces

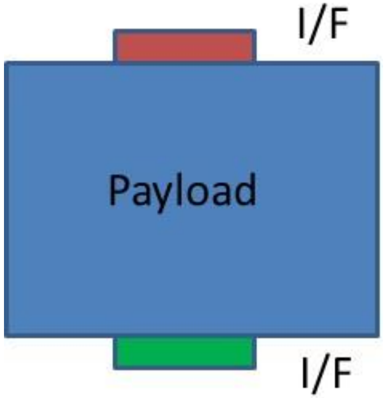
Robotic Interfaces for Transport

<u>JEM RMS Interfaces</u>
Flight Releasable Grapple Fixture

<u>Small Fine Arm Interfaces</u>
Tool Fixture 1 or 2

<u>SPDM Interfaces</u>
H-fixture
Micro-Square
Micro-Conical

<u>SSRMS Interfaces</u>
Flight Releasable Grapple Fixture
Latchable Grapple Fixture
Power and Video Grapple Fixture



Interfaces for Launch or ISS Location

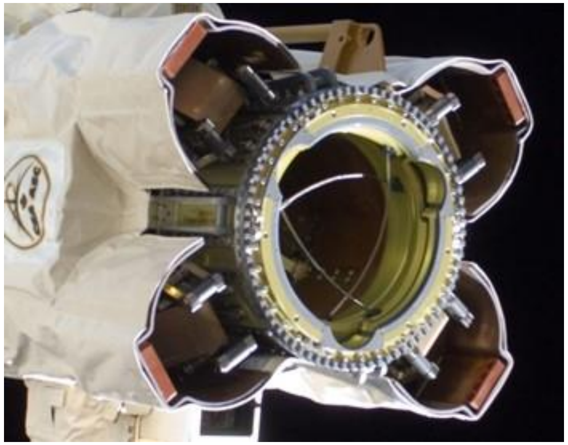
Internal stowage, FRAM, JEM EFU, Payload Unique

SSRMS Interface Hardware

- For payloads that require a direct interface with the SSRMS (or POA or SPDM LEE), there are a few different interfaces to be aware of:
  - Flight Releasable Grapple Fixture (FRGF)
    - **Simplest grapple fixture – only allows for grapple**
  - Latchable Grapple Fixture (LGF)
    - **Allows for grapple and latching**
    - **Intended to be used for longer-term stowage on the POA (greater than 3 weeks)**
  - Power and Video Grapple Fixture (PVGF)
    - **Allows for grapple, latching, and access to data, video, and power**
    - **Connectors for data/video/power integrated into the fixture**
  - Power and Data Grapple Fixture (PDGF)
    - **Allows for grapple, latching, and access to data, video, and power**
    - **Connectors for data/video/power integrated into the fixture**
    - **Only fixture that is an On-orbit Replaceable Unit (ORU)**

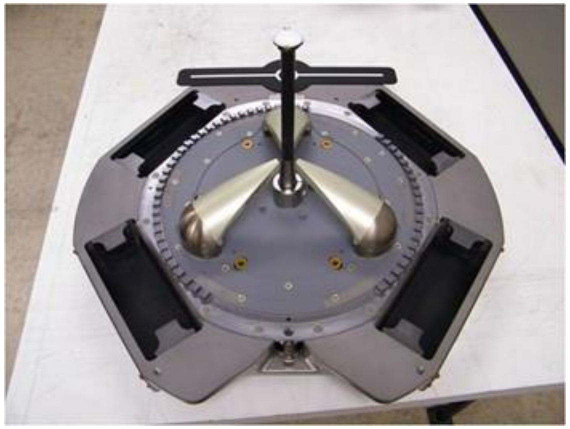
SSRMS Interface Hardware

FRGF

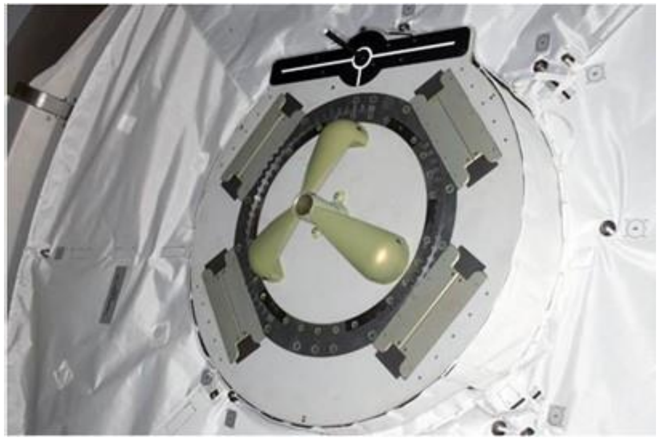


LEE

PDGF (no longer provided)



LGF



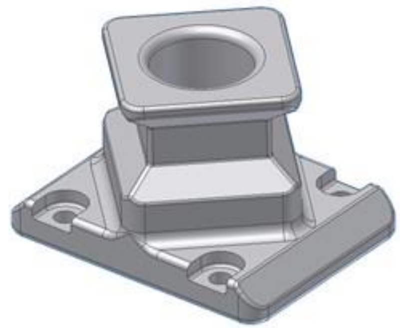
PVGF (grapple shaft not shown)

SPDM Interface Hardware

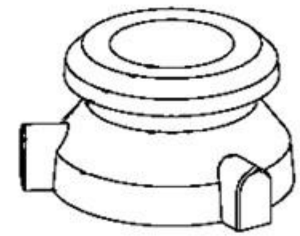
- For payloads that require a direct interface with the SPDM, there are a few different interfaces to be aware of:
  - H-fixture – allows for direct grasp by SPDM ORU Tool Changeout Mechanism (OTCM)
    - **Typically used on heavier payloads or where a "beefed up" interface is required (assumes attachment structure can withstand the higher loads)**
    - **Allows for use of an umbilical connector and/or a co-located bolt**
    - **Requires enough space to accommodate the SPDM OTCM**
  - Micro-fixture (also known as a Micro-square) – allows for direct grasp by SPDM OTCM
    - **This is the "standard" grasp fixture**
      - **MMF found on FRAMs is a version of this fixture**
    - **Allows for use of an umbilical connector and/or a co-located bolt**
    - **Requires enough space to accommodate the SPDM OTCM**
  - Micro-Conical Fitting (MCF) – allows for grasp by Robot Micro-Conical Tool (RMCT)
    - **Used when there is not enough space for the SPDM OTCM to access the fixture, but requires the SPDM to acquire a tool (RMCT) which has operational overhead associated with it**
    - **Allows for use of a co-located bolt, but not an umbilical connector**
  - Modified Truncated Cone (MTC) Target
    - **Co-located with the grasp fixture and used to line up SPDM OTCM/RMCT for grasping**
      - **Other target types are listed in documentation, but this is the standard target type**
    - **Requires enough space to allow unobstructed viewing during approach**
  - Umbilical Connector
    - **Provides access to power, data, and video connections through the SPDM OTCM**
    - **Cannot be used in conjunction with an MCF**

Interface Hardware (cont.)

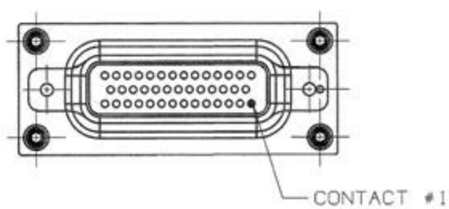
H-Fixture



Micro fixture



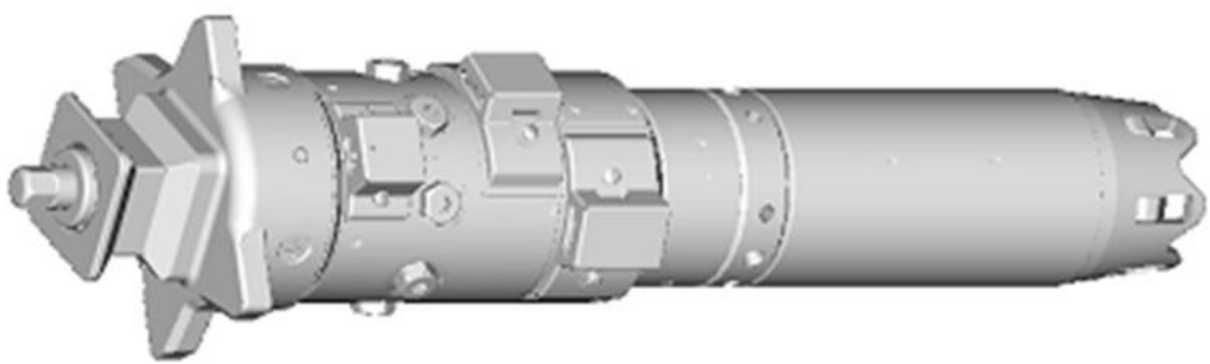
Micro-Conical Fitting (MCF)



User Umbilical Connector

Modified Truncated Cone (MTC) Target

Robot Micro-Conical Tool (RMCT)



SPDM Interface Hardware

Grasp fixture selection criteria

Discriminators	H-fixture	MSF	MMSF	MCF	MMCF
— Grasp Fixture has clearance to be grasped directly by OTCM (no tool needed) — Payload needs access to power, data, &/or video resources	X	X	X		
— Maximum interfacing moments are expected to exceed 125 ft-lbs	X				
— Payload needs collocated bolted w/ locking mechanism			X		X
— Must use RMCT because OTCM cannot access grasp fixture due to restrictive location				X	X
— Must use ROST because OTCM cannot access grasp fixture bolt due to restrictive location		X	X		

Question: Which robot (SSRMS or SPDM) do you use?
Answer: Primarily driven by mass handling requirements

- SSRMS designed to handle the Orbiter (~200,000+ lbs.)
- Envelope, CG, Inertia, Mass for SPDM operations shown below

SSP 57003, TABLE 3.7.4.2-1 PAYLOAD PARAMETERS FOR DEXTEROUS OPERATIONS

Maximum Mass [4] lbm (kg)	Maximum Inertia [1] lbm-ft2 (kg-m2)			Maximum CG Offset [2] in (m)			Maximum Dimension ft (m)			Minimum Freq [3] (Hz)
	Ixx	Iyy	Izz	CG^x	CG^y	CG^z	X	Y	Z	
1320 (600)	1186 (50)	1186 (50)	1186 (50)	19.7 (0.5)	9.8 (0.25)	9.8 (0.25)	5.25 (1.6)	5.25 (1.6)	5.25 (1.6)	8

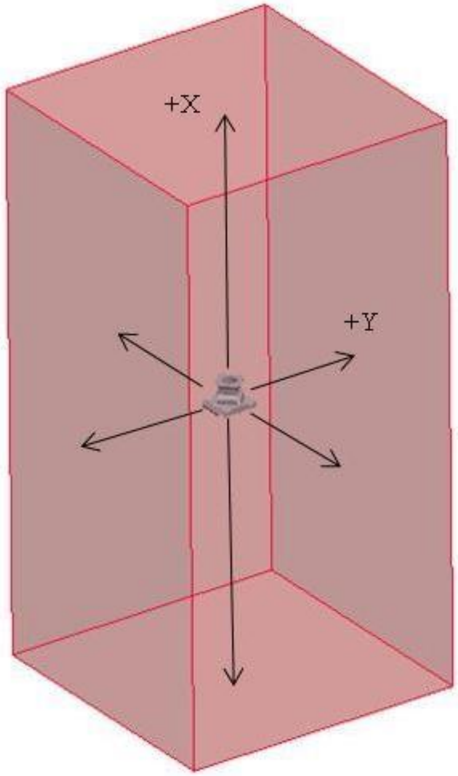
Notes:

1 Moments of inertia are expressed about the attached payload integrated assembly CG in the payload principal axes.

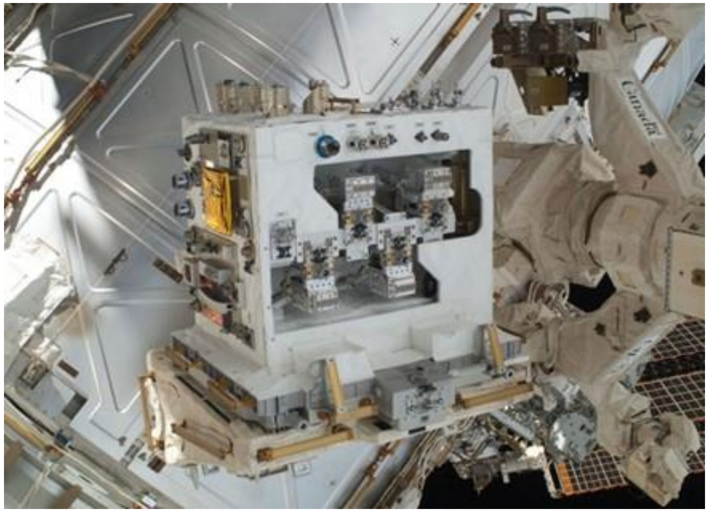
2 Center of gravity offset is defined as the vector from the attached payload integrated assembly center of gravity to the origin of the coordinate system associated with the SDGF.

3 Minimum attached payload integrated assembly frequency, assuming that the grasp fixture is held rigid.

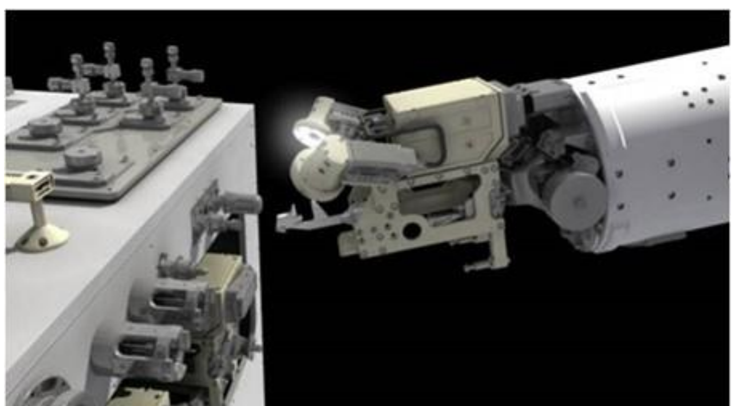
4 Mass of the attached payload integrated assembly.



Payload Examples of Robotic Interfaces

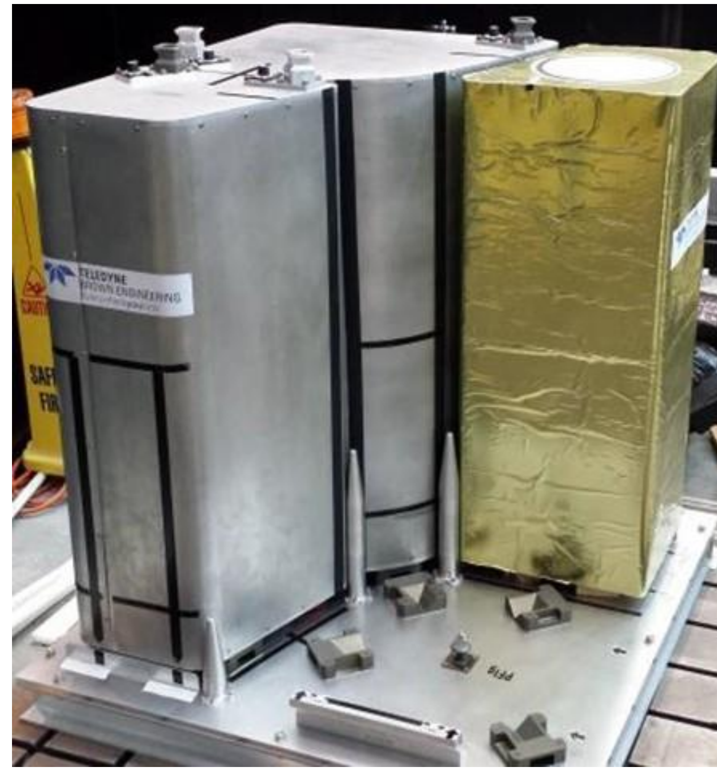


Robotic Refueling Mission (RRM) is a FRAM based payload (on SPDM EOTP for transport)



RRM uses SPDM as part of the payload to perform refueling tasks. RRM built unique tools for the SPDM

SPDM to payload I/F – Micro Fixture



Since the individual components are intended to be changed out robotically, the payload to FRAM I/F must be robotically compatible

Robotics Forums (How To Get Started)

- DRIT – Dexterous Robotics Integration Team
  - Mondays, 2:00 PM Central
  - Co-chairs: OM7 and CSA
  - https://iss-www.jsc.nasa.gov/nwo/seio/robotics/home/web/DRIT.shtml

- SIT – SSRMS Integration Team
  - Wednesdays, 1:00 PM Central
  - Co-chairs: OM7 and CSA
  - https://iss-www.jsc.nasa.gov/nwo/seio/robotics/ebit/web/

- MSS SEWG – MSS System Engineering Working Group
  - Every other Tuesday (generally alternating with the MIP), 8:30 AM Central
  - Co-chairs: ER3 and CSA
  - https://iss-www.jsc.nasa.gov/nwo/seio/robotics/home/web/SEWG.shtml

- MSWG – MSS Software Working Group
  - Every other Thursday, 1:00 PM Central
  - Co-chairs: OD and CSA
  - http://iss-www.jsc.nasa.gov/nwo/avionics/ip/home/web/MeetingInformation.shtml

- MIP – MSS Integration Panel
  - Every other Tuesday (generally alternating with the MSS SEWG), 8:30 AM Central
  - Co-chairs: OM7 and CSA
  - https://iss-www.jsc.nasa.gov/nwo/ppco/cbp/web/mip.shtml

Robotics Forums

- Why go to the DRIT?
  - Review of SPDM-related analysis (MAGIK, CSA, etc.)
    - **For example, fixture location and manifest location**
  - Requests for or exchange of SPDM-related information
  - Review SPDM-related requirements exceptions
  - Review of SPDM-related schedules
  - Track the need for other subsystem analyses prior to performing dexterous ops
  - Primary participants: OM7, CSA, ER3, MOD Robotics

- Why go to the SIT?
  - Review of SSRMS-related analysis (MAGIK, CSA, etc.)
    - **For example, fixture location and manifest location**
  - Requests for or exchange of SSRMS-related information
    - **Grapple fixture substrate loads for example**
  - Review SSRMS-related requirements exceptions
  - Review of SSRMS-related schedules
  - Primary participants: OM7, CSA, ER3, MOD Robotics

Robotics Forums

- Why go to the MSS SEWG?
  - Technical discussions of system-wide topics
  - MSS requirements technical discussions
  - Primary participants: ER3, CSA, OM7, MOD Robotics, Safety, Crew Office

- Why go to MSWG?
  - Payload data or commanding through the MSS
  - Primary participants: ISS Software & Avionics (OD), CSA, OM7, ER3, MOD Robotics, Safety, Crew Office

- Why go to the MIP?
  - "Front door" to the ISS Program for robotics-related topics
  - Introduce new payloads to NASA and CSA robotics community
  - Requests for information that could not be provided through the DRIT or EBIT
  - Review of MSS schedules
  - Review of MSS changes
  - Primary participants: OM7, CSA, ER3, MOD Robotics, Safety, Crew Office, ISS Software & Avionics (OD)

Robotics POCs

- The robotics community (ER3, OM7, CSA, and MOD) is here to help. This slide has all the robotics POCs. CSA and MDA are the technical authority on the MSS and are engaged via the various robotics forums as shown on the previous slides

- ER3 – Robotics System Management and Engineering Support
  - MSS System Manager – Larry Grissom (281-483-9525, larry.w.grissom@nasa.gov)
  - Deputy MSS System Manager and SSRMS Subsystem Manager – Glenn Jorgensen (281-244-6565, glenn.jorgensen-1@nasa.gov)
  - SPDM Subsystem Manager and SPDM Requirements lead – Michael Wright (281-483-4798, michael.d.wright@nasa.gov)
  - SSRMS Requirements lead – Kendrick Cheatham (281-244-6744, kendrick.cheatham-1@nasa.gov)

- OM7 – Robotics System Engineering and Integration
  - Manager, Robotics Integration Office – Michael Berdich (281-244-7957, michael.a.berdich@nasa.gov)
  - Robotics System Integration Lead – David Read (281-244-2212, david.read-1@nasa.gov)
  - JEM Airlock Integration Lead – Chris Wade (281-244-2812, christopher.d.wade@nasa.gov)
  - Software Integration Lead – Deep Patel (281-244-8269, deep-patel-1@nasa.gov)

Conclusion

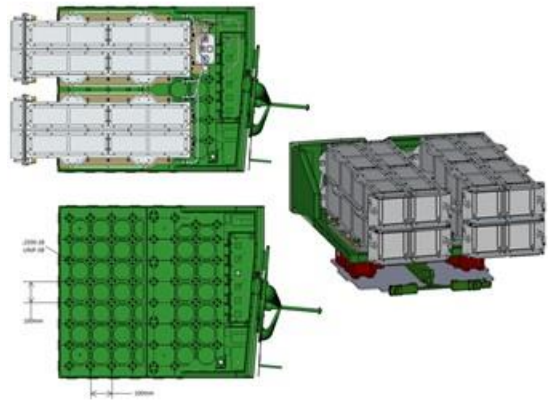
- Robotic systems are available to support payload installation, operations, and removal.
- Robotic systems provide a lot of flexibility and options for payload users in order to meet their objectives.
- However, that flexibility also means there is additional complexity in the trade space for what options and services to utilize so working early with the robotics community is strongly encouraged.
- In addition, there are multiple compatibility requirements (such as loads, viewing, thermal clocks, etc.) that must be met that can be worked in the robotic forums.

Backup

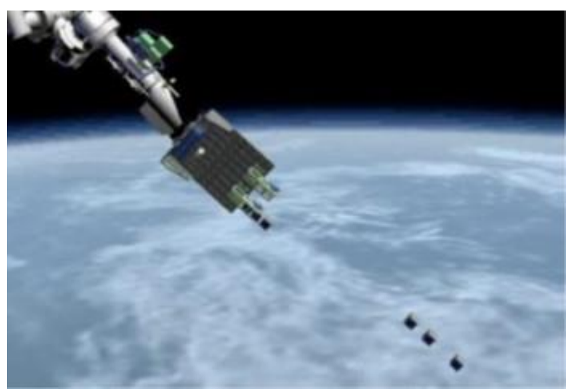
Micro/NanoSats Deployers

Deployable payloads utilize Cyclops, NRCSD, or JSSOD (all nominally use JEMRMS) to interface to the Airlock table

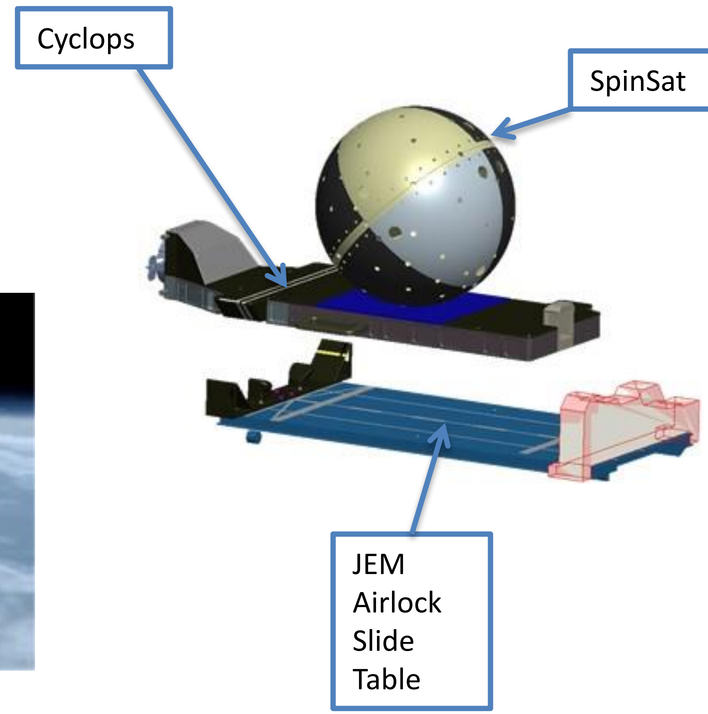
JSSOD



NRCSD



Nanosat Deployment
Using JEM RMS



Flight Releasable Attachment Mechanism

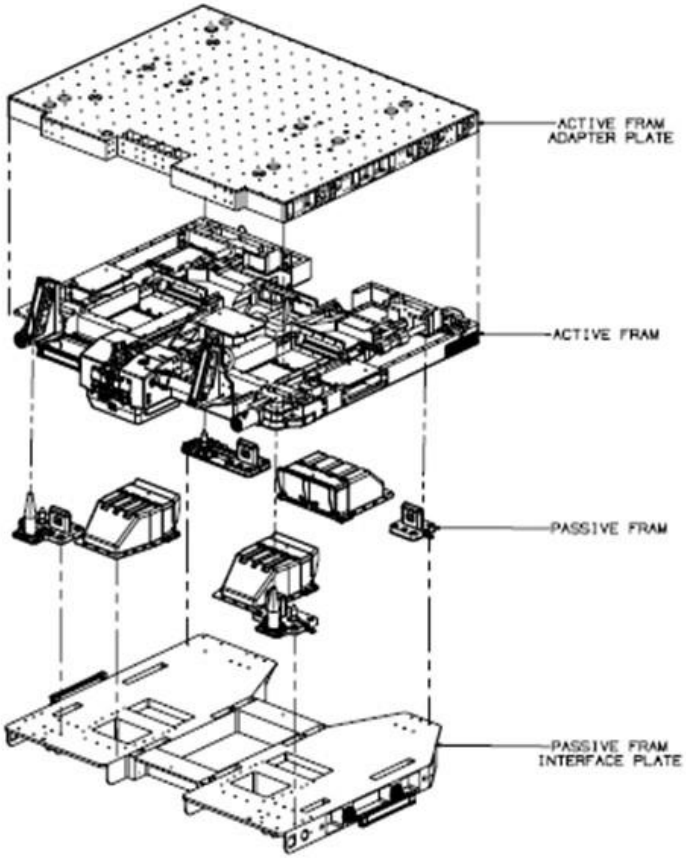


FIGURE 1-3. FRAM System – Exploded View

- Passive FRAM components mounted to carrier interface
- ORUs mounted to FSE on top of Active FRAM Adapter Plate
- Figures taken from FRAM IDD, D684-10822-01, Rev A